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REVIEW

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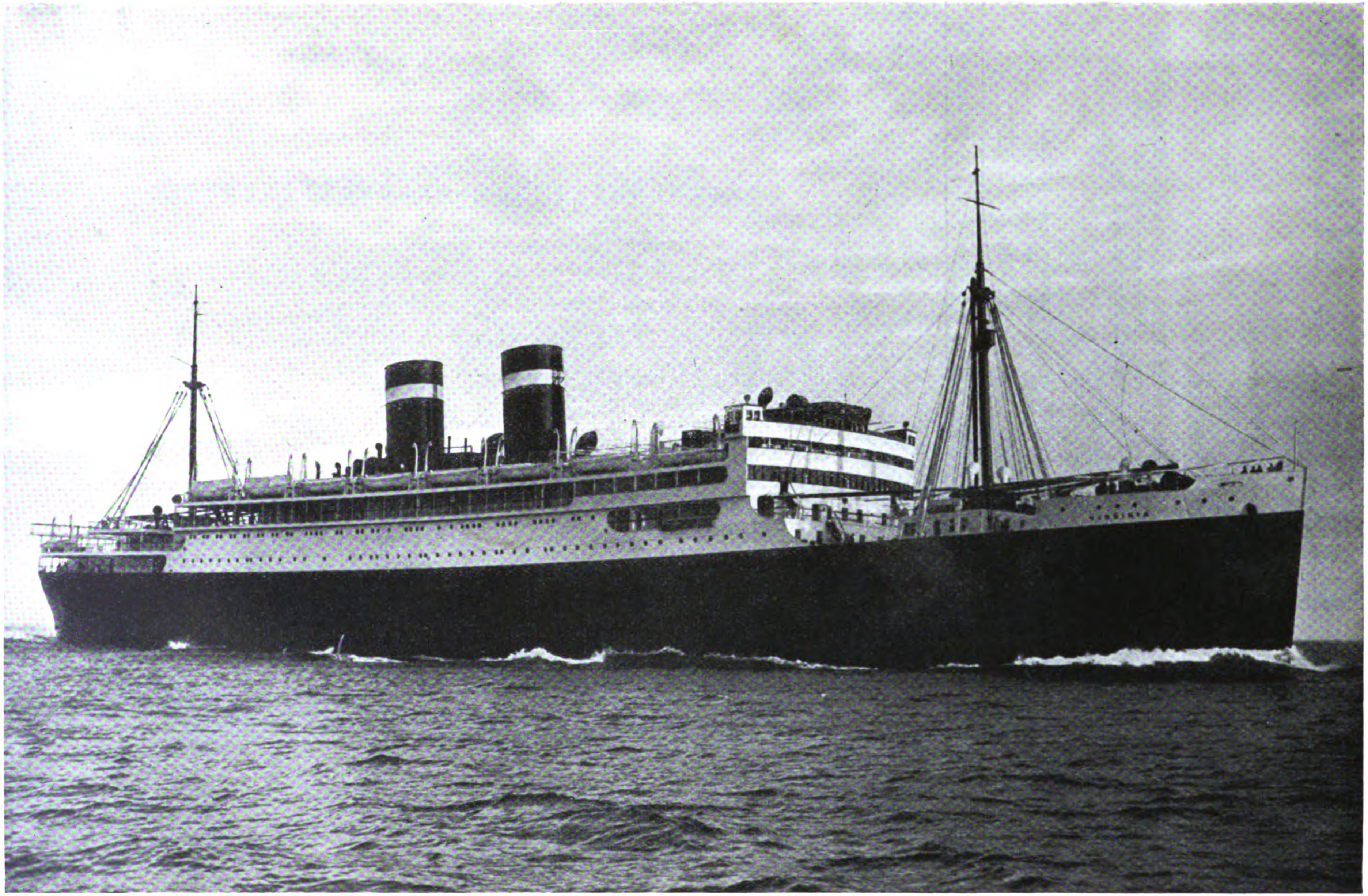

The All-electric Passenger S. S. *Virginia* on Its Acceptance Run

GENERAL ELECTRIC REVIEW

Vol. 32 January, 1929 No. 1

AGES AND AGES

Our world is a little waltzing ball on an eternal joy-ride through space. Whence it came and whither it goeth no man can tell; but probably every single atom, from central core to loftiest mountain peak, including the minutest part of everything alive and dead, was in its remotest past in the state of an incandescent gas radiating light and heat energy throughout the realms of infinite space.

The inimitable Slossan was more of the philosopher than humorist when he penned his delicious parody—

"Twinkle, twinkle, giant star,
I know exactly what you are,
An incandescent ball of gas
Condensing to a solid mass."

Our parent, the Sun, with its insignificant diameter of but 866,000 miles, was, at one phase of its evolution, a giant star of sufficiently respectable a diameter to rank with the other giants of heaven, whose diameters measure a few hundred million miles. In density our Sun then probably vied with Betelgeuse today in being many times rarer than the best vacuum we can make on earth with a Langmuir pump.

If we accept the most tenable theory of how the earth came into being we must visualize it; together with its brother and sister planets, Mercury, Venus, Mars, Jupiter, Saturn, Uranus and Neptune, as being "bits" of their parent Sun flung into space. How small "a chip of the old block" our earth is can best be realized when we state that its bulk must be multiplied one million and a quarter times before it equals that of the Sun, and, again, when we remember that its diameter is less than 8000 miles, or equal to about only four times the round trip between New York and Chicago.

Our little "ball of incandescent gas" must have taken ages and ages to "condense to a solid mass." How long, no one can give even an intelligent guess; but when its surface started cooling the first page of Dame Nature's great terrestrial history book was written.

There is more than mere idle poetic fancy in calling the rocks "the Manuscripts of God," as each successive layer of rock reveals the history of the age in which it was formed and the history of life as it existed at that particular period. When read correctly, these "Manuscripts" reveal the grand history of evolution from single cell to Man.

Our first page of history must have been written when a small part of the earth's surface started cooling —when the oldest rocks, the Fundamental Gneiss, were started. Then most of the earth must still have been a boiling, boisterous, effervescent, molten mass far too hot for any sea to exist. In those remote days the waters that form our present seas and oceans surrounded our globe as dense, whirling clouds of superheated steam.

Beneath this blood-red canopy of fire-illuminated steam our first rocks must have congealed as a hot crust over a seething, glowing liquid in much the same way as so recently was witnessed when the crust formed over the stream of molten lava as it poured down the slopes of Mount Etna on its errand of destruction.

There must have been a long succession of coolings, solidifications, remeltings, recoolings, crystallizations and recrystallizations before the first appreciable film of rock was formed. In those days the earth must have been like some untamed, unnamed monster quivering in the agonies of giving birth to a new world. The ways of the Creator are always beyond the comprehension of Man, for from those tempestuous hurricanes, whirlwinds, and multitudinous volcanic eruptions and upheavals (that must have been the order of those days) our habitable earth was born.

In even thinking of this period we must draw on our imaginations and read a few million, or a few hundred million, years between each line. But as the crust of the earth cooled a little we can visualize the steam in the atmosphere as starting to condense; now and then some of it falling to the hot surface of our globe, mostly to raise again in hot vapor, but some flowing over the hot rocks and, in its passage to the depressions in the surface, carrying with it in the dust and rock debris that form a sediment in the world's first ponds—possibly the forerunners of our seas. This sediment accumulates layer by layer (strata) and so the first Sedimentary Rocks which cover the earth today were formed.

Each succeeding layer of rock denotes a geologic age, and it is of special interest to note that each age is named with reference to the evidences of life found in the rocks then formed. If we made an inspection of the rocks after the Fundamental Gneiss we should come to:

(1). The Lifeless Rocks (Azoic) so named because it was for many years thought they bore no signs of life; but since graphite and red and black oxides of iron have been found in these rocks, and as it is quite generally supposed that these require the agency of living things for their production, many prefer to call our first Sedimentary Rocks the Primordial Life Rocks (Archæozoic). It should here be noted that most likely the very earliest forms of life had insufficient structure, that is to say, had no skeletons, and were therefore too soft to leave remains for us to examine today.

(2). The second series of Rocks were the "Beginning of Life Rocks" (Proterozoic). These contain definite evidence of the simplest and earliest forms of life as we know it. They reveal remains of the simple plants—the Algæ, and marks that look like the tracks of worms in sea mud as well as the skeletons of those microscopic creatures called Radiolaria. This was the age of Animalcula and Green Scum when probably such things as jellyfish came into existence.

(3). The third series is called the Ancient Life Rocks (Palæozoic) and contain a wealth of evidence of life. In them we find the remains of a wide variety of shellfish, crabs, worms and seaweeds, and then, after a multitude of fishes, the beginning of the land plants and land animals. It was in this period apparently that life first came from the water to invade the surface of the land; it was an age of Amphibia and Swamp Forests.

(4). Next came the Middle Life Rocks (Mesozoic). They are rich in fossils and it is here that we find the bones of those giant reptiles that came into existence, multiplied exceedingly, became undisputed masters of the earth, and then became extinct. In this age our earth was peopled by those huge lumbering things, the Saurians, the Ichthyosaurus, and Dinosaur, that flesh-eating monster, the Rex Tyrannosaurus, and the Iguanodont and many other slow-witted creatures with crack-jaw names. It is in these Rocks also that we find the remains of Pterosaurs, notably the Pterodactyl, and those other reptiles that learned to fly a few million years before man. Many of those huge reptiles, whose length may have exceeded a hundred feet and who weighed many tons, were armoured-plated like battleships; but one and all, small and large, were slow-witted, small-brained creatures—so all perished. They could not compete with the Creator's latest design, the Mammals; only the fit can survive, so the giant reptiles became a bankrupt species and all we know of them today is from their bones that we find in the rocks.

(5). The Fifth, and last in series of great ages, as divided by the huge deposits of Sedimentary Rocks, are the Recent Life Rocks (Cainozoic). This is our unfinished volume which the great and little rivers of today are still adding to, leaf by leaf, as they carry their sand and mud to the sea. This is our age—the Age of Mammals.

Opinions differ greatly as to how long our set of volumes took to complete. Estimates vary from 25,000,000 to 1,600,000,000 years. The weight of modern evidence is perpetually pointing to the higher estimate as more likely to be correct.

The age of the Recent Life Rocks (Cainozoic) is now usually divided into five periods, but we must state these only very briefly:

(*a*). The Eocene Period. A study of the rocks laid down in this period shows that it was now that higher-type Mammals appeared and the older types of life vanished completely.

(*b*). The Oligocene Period. During this period the Anthropoid Age appears on the stage of life.

(*c*). The Miocene Period. This Period witnessed the culmination of the Mammals and was the period when some of our mightiest mountain ranges were built and when the temperature began to fall.

(*d*). The Pliocene Period. This period witnessed the transformation of Man-like Apes into Man, and the climate of the earth became very similar to what we experience today.

(*e*). The Pleistocene Period. This was the great Ice Age when the world witnessed four great glacial periods and the extinction of the Great Mammals. It was also the Age of the Dawn of Mind, when man evolved his first industries and became an artist. Our ancestors, The Men of the Stone Age, during this period by learning to protect their skins, and to use their hands, feet, mouths, ears, and eyes, laid the true and first foundations on which all the achievements of Man, from the Dawn of Mind to the present, have been built; and on which all the achievements of the future will rest.

The beginning of the Pleistocene Period was probably 550,000 years ago, and the first second, third, and fourth glacial periods are probably respectively 500,000, 400,000, 150,000, 50,000 years old now.

In the eons of time when the earth was cooling down, and even possibly when life had started in the green scum floating on the surface of an almost boiling sea, the sun itself must have been much hotter and the earth must have been revolving faster, making shorter days and shorter nights, and possibly the years were shorter too. The heat must have been terrific, and the storms, earthquakes and volcanic disturbances must have been beyond the imagination of man. The moon was both brighter and closer to the earth in those remote ages.

It was the classical researches of such men as Penck, Bauckner, Geikie, Chamberlin, and Leverett, that established, beyond all reasonable doubt, the eight subdivisions of the Pleistocene Period, *e.g.*, four glacial, three interglacial, and one postglacial.

After all the eons of time since the world started cooling, and after the ages and ages of life on the earth, when did Man step upon the stage to start his dramatic career and to "have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth and over every creeping thing that creepeth upon the earth?"

The Heidelberg jaw may be 250,000 years old, the Piltdown skull may be 100,000 years old, the Neanderthal man may be 50,000 years old. But it is *only* "maybe." We believe there is no definite evidence of anything remotely like a present-day human being on our earth more than 100,000 years ago.

When we consider the successive cultural periods of man and his industries, the first is named Eolithic and is the period when worked stone implements were first used. But it is hard to assign a date other than to say "it may have been 100,000 years ago." Henry Fairfield Osborn has written a most excellent book on "Men of the Old Stone Age," that Age (The Palæolithic Age) of which we have abundance of evidence and so many fascinatingly interesting relics collected from the rocks. He describes the earliest stone implements (or nearly the earliest) that show that man was becoming an intelligent being, and, by the use of his hand, had started developing the brain which was going ultimately to make him the overlord of all created things on earth. The Palæolithic Period probably lasted till from approximately 100,000 to 12,000 years ago.

Then we come to the New Stone Age (Neolithic) of which we find so many and various relics, and the most remarkable evidence is found now of the improvement in man's skill and technique in fashioning his weapons and implements of stone. The probable date of this period is from 7000-8000 to 2000-3000 years ago. The latter part of the New Stone Age merged into the Bronze Age, which lasted till about 2000 years ago and in some countries survives today. Here we may add in parenthesis that in Judaea the transition from the later Stone Age into the Bronze Age probably occurred during the life of King David, the Psalmist—He slew Goliath with a stone, but Hebrew writers loved to tell of the might of David's sword and of his shield and spear!

Now, only approximately 2000 to 3000 years ago, the Iron Age, which lasted through Roman times up to the present, began, and so we have arrived at our own times. The two most striking facts that even such a brief review of the Ages brings to light are: *(1) that man is still the latest novelty on the earth; (2) that all the wonderful products of science and invention are the children of but yesterday.*

Of the one billion years since our earth has probably been cool enough to support life in some form, the last one or two centuries, when our progress has been so immense and so rapid, is such a tiny fraction that we are literally correct when we say that we have only just started on our march of progress.

We have called our earth a little waltzing ball on an eternal joyride through space, and we feel that our rate of progress in the future will be much greater than in the past. We feel that in a few centuries our earth is going to be an astonishingly different place to live on—a much pleasanter place.

Ages and Ages have passed—what about future Ages? The contemplation of them opens up such a vast field for the speculative imagination that it is impossible to enter it without imposing rigid limits. But let us consider briefly just one age that we feel sure is coming in the not too distant future—The Age of Biology.

THE AGE OF BIOLOGY

In the Age of Biology, which sometimes seems to us destined to be the greatest of all ages, because now it is so hard to penetrate further into the future, man will have found the secret of life itself. It will be possible in that age, if not actually to produce life synthetically, to understand and control life processes. The consequences will be stupendous.

The thoughts of each age from now onward will be the foundations on which the succeeding age is built. Man almost unknowingly produced the cereals, which are his staple food, from the grasses, gradually increasing the size of the seed or grain by successive cultivation, until today corn is called the King of the grasses and wheat the Emperor of grasses. In the Age of Biology, when life processes are better understood, each stalk of wheat should render a many-fold harvest. The but slight increase in size of the individual grain will lead to an immense increase in the wealth of wheat- and corn-producing countries.

The beautiful chrysanthemum was developed by the intelligent successive cultivation of a tiny daisy, and the glorious double rose from the familiar dog rose of our hedges. These accomplishments and those of such men as Luther Burbank and his school have already pointed the way to what one may expect in the Age of Biology.

In that age man will no longer be content to burrow and drill to the depths of the earth for his solidified and liquified sunshine, the product of the sun's rays in bygone ages; he will give up depending almost entirely on the fossils of the past ages for fuel. He will *grow* his fuel in the Age of Biology. That single fact will probably change the political map of the world. There will be a scramble then for the belt of land on either side of the equator where the vertical rays of a tropical sun will be capable of raising all the fuel man requires the same year that it is used.

Probably in that age, man with a better understanding of life and life processes will cultivate luxuriant growths of seaweed in every ocean and thus coax the sea to yield a much larger share of our daily food than at present in the form of fish. In the final analysis, all fish feed on seaweeds, the little fish feed on the broken bits of weed on the littoral, and bigger fish on the little fish, until finally we find that the shrimp, the cod, and whale alike depend for life on the weeds of the sea.

When the Age of Biology is well established it is likely that a large proportion of our food will be made synthetically in factories and will contain all the necessary vitamins with great benefit to the health of all.

When life processes are better understood and brought under the control of man, the possibilities of new species in the vegetable world, including flowers and trees, are quite unthinkable, and the consequences beyond our imagination.

In that age, man will have eliminated the serious ravages of all infections and contagious diseases.

Celular physiology is making progress and man is a mighty elaboration of multitudinous cells. The most serious thoughts come to our minds when we contemplate what man may do for the animal kingdom, including man, in the Age of Biology. We need not walk all the way with Haldane and Lodovici into the realm of synthetic children. But in between the lines of the brilliant pyrotechnics and wit of Haldane and the scathing irony of Lodovici there is plenty of room for serious thought.

The chemical routine, or metabolism of man changes in mid-life, the anabolic processes slow down, and the katabolic processes increase their activity. We don't die suddenly—Shelley was a good doctor as well as a good poet when he wrote:

> "First our pleasures die, and then
> Our hopes, and then our fears, and when
> These are dead, the debt is due.
> Dust claims dust, and we die too."

With an increase in knowledge of all the organs and glands of our bodies, especially the ductless glands and their hormones, those messengers of life, health, and happiness, together with the elimination of many scourges of disease that have afflicted mankind in the past; coupled with advances in bio-chemistry, biophysics, medicine and surgery, man can look forward with confidence to a great extension of life in the Age of Biology.

The human body is a chemical factory, and life in its varied forms is the most complex expression of the transformation of matter and energy. From birth till we return to dust, we are transforming carbohydrates, fats, proteins, salts, and water with every heart-beat and with every breath we draw. The human body is colloidal, and colloidal chemistry is a new science. With further advances in this new science and with increased knowledge in the use of the sun's rays, and artificially produced ultra-violet and other rays, we can be confident of marvelously better health and longer life in the Age of Biology.

But it is not the extension of life beyond the biblical three score years and ten that we hail with so much joy as the fact that the whole period of life will be much more useful and more worth-while.

With the curtailment of disease and the better understanding of life processes, a young man will be better physically, morally, and intellectually, and therefore be a greater blessing to himself and to the world as a whole. Older men will retain their health, vigor, and useful faculties almost up to the time they die a natural death. Death is as natural as birth and as life itself and is no more to be dreaded or regretted. It is the impairment of life's usefulness and the premature death of those that might live useful and happy lives that is to be mourned.

In the Age of Biology man will have banished the taboo of fear by the light of knowledge and will retain his pleasures, hopes, ambitions, and usefulness throughout the period of his natural life.

As our January issue comes off the press just about Christmas time, besides sending our readers this message of hope and confidence in a happier future, we wish them, one and all, a Merry Christmas and a Happy and Prosperous Year. J. R. H.

Some Developments in the Electrical Industry During 1928

By JOHN LISTON
General Electric Company

THE year 1928 exceeded all previous years in its volume of production of electrical equipment. The dollar value of the total product was also increased in spite of the fact that, due to numerous improvements in manufacturing methods, it was possible to effect reductions in the prices of certain classes of apparatus and incandescent lamps. Advances in design and improved materials resulted in increased efficiencies in practically every phase of the industry from the generation, transformation, and distribution of electric energy to its application and control.

A 94,000-kw. tandem compound unit, the largest completed unit of its type, was placed in service, and work was nearing completion on a 160,000-kw. tandem compound and a 208,000-kw. cross-compound unit, each representing the maximum capacity in its type.

As the result of several years' experience with relatively small steam-turbine generators operated at 1200 lb. steam pressure in combination with low-pressure steam systems, it was possible to design large machines of this type to serve as the main generating units for two important central-station systems.

In the marine field, the second large all-electric passenger liner, *Virginia*, was placed in commission; and the equipment for two additional ships for this same class of service was under construction. The appreciation of the value of electric propulsion was further evidenced by the construction of two seagoing craft by England and Italy. With the exception of a fuel-ship for the Japanese Navy, these ships are the first large foreign craft to adopt electric propulsion.

The electric battleship *New Mexico* for the second time was awarded the yearly battle efficiency pennant, and the 180,000-s.hp. aircraft carriers *Saratoga* and *Lexington* each exceeded all previous speed records for capital ships, both over the measured mile course and during the transit of the Pacific between California and Honolulu. The *Lexington* established a new record for power applications on ships by actually developing 210,000 shaft horsepower.

The work of electrifying the main lines of steam railroads was continued by the completion of the Boston, Revere Beach and Lynn Railroad, and by additional mileage for the Great Northern Railroad. Rapid progress was also made in the Cleveland Union Terminal's electrified railway project. Late in the year, public announcements were made by the Delaware, Lackawanna and Western, the Philadelphia and Reading, and the Pennsylvania Railroads in regard to their plans for the early extension of electric operation.

The oil-electric locomotive and the gas-electric type of railroad car were both adopted in larger numbers than in any preceding year. The first main-line freight locomotive of the oil-electric type was placed in service.

Concurrently with the increase in the mileage of our lighted airways, the lighting units for both route and landing field service were standardized, and more powerful beacons and floodlights were provided to increase the factor of safety in landing at airports. There were also developed a device which enables the aviator to determine his elevation above the ground by means of radio impulses, an ingenious type of magneto compass operating on a new principle, and a mechanism which permits the measurement of gasoline in airplane tanks with a high degree of accuracy while in flight.

The outstanding accomplishments in research include the use of the lightning-actuated type of cathode-ray oscillograph, which was applied in the study of lightning phenomena in the field on a truly engineering basis, the production of a 50,000,000-cycle tube with a ten-kilowatt output, and photoelectric tubes of greatly increased sensitivity, which have aided in the notable advances made toward the achievement of practical television. The use of vacuum tubes for purposes other than radio communication was extended to such diverse applications as the control of furnace temperature, the automatic leveling of elevators, and the remote indication, control, and supervision of the equipment of power stations and substations.

Radio television broadcasts were made at least twice a week during the second half of the year, and a developmental household type of television receiver was produced. A notable indication of the practical advances made was the transporting of television receiving apparatus and its use many miles from the transmitting station to televise the speakers at a meeting of national importance. This is probably the first instance of the field use of portable television equipment. Other radio developments worthy of note were daily tests of transcontinental facsimile telegraphy, and, on three occasions, the maintenance of two-way telephone communication with Australia for periods of about one hour.

There were also specially-designed aircraft radio sets produced, suitable for use in single-seaters, heavy bombing airplaines, and dirigibles.

The automatic control of generating equipment was applied to a hydroelectric station of 100,000-kv-a. capacity; and the mercury-arc power rectifier was improved in both capacity and performance and utilized in automatic substations to a greater extent than in previous years. A feature of great potential value was the development of a practical and simplified form of outdoor substation for farm service, which enables the farmer to receive current at normal operating voltages directly from high-tension transmission lines. Series capacitors were utilized, for the first time on a commercial basis, for compensating the reactance on a transmission line.

Electric welding superseded the noisy riveter in the erection of the steel framework for a number of buildings, and was also utilized for bridge construction.

In presenting a review of these and the many other developments which occurred during the year, all the apparatus referred to are products of the General Electric Company. These cover such a wide range that the references will serve as an indication of the tendencies in design and construction as well as the general progress in the electrical manufacturing industry as a whole.

TURBINES

High-pressure

The year was notable for the advent of the first two all-high-pressure stations equipped exclusively with 1400-lb. boilers and large 1200-lb. turbines.

A thorough study had been made of the dollar economy of various steam pressures and cycles of operation, and as a result the turbines will have steam conditions of 1200 lb., 725 deg. total temperature with boiler reheat to 750 deg. between the high and low pressure elements of the cross-compound turbines. Economy data from ten representative high-pressure and high-temperature power plants have shown a practical realization of the theoretical gains resulting from higher steam pressures and temperatures.

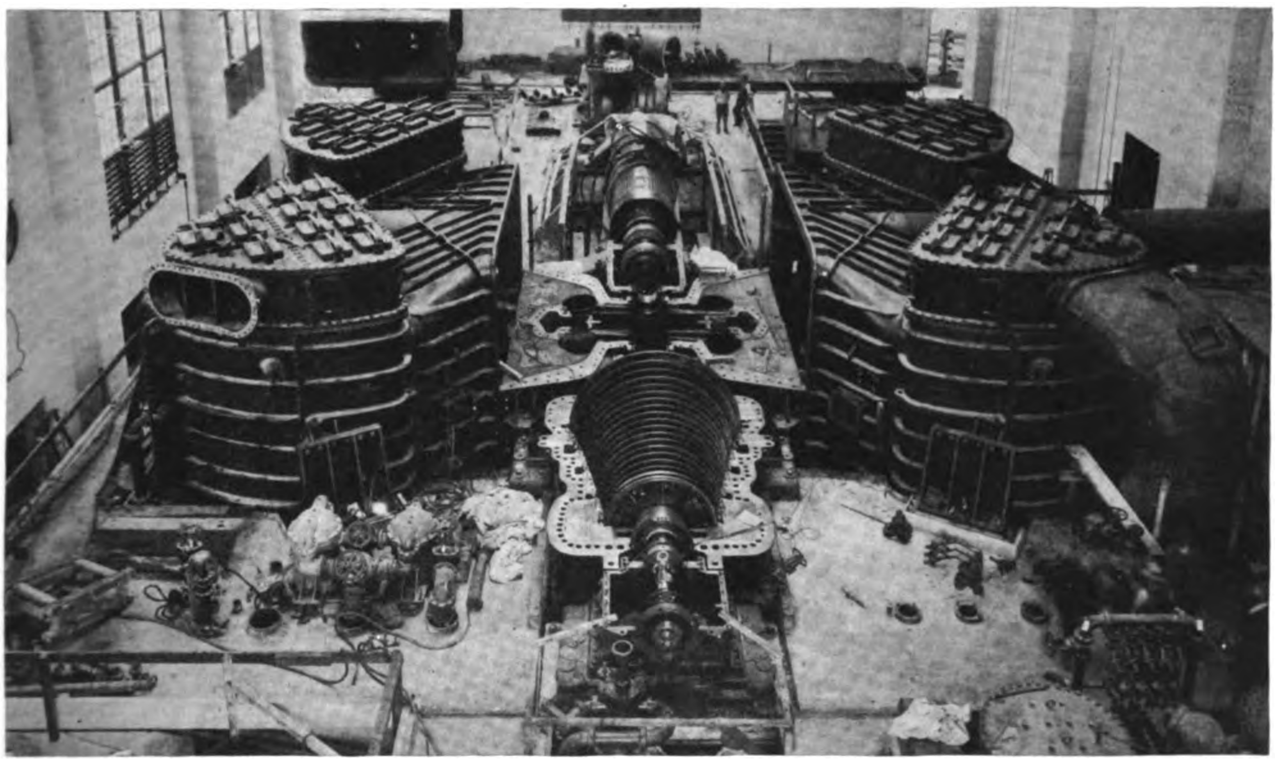

Fig. 1. Installing the First 94,000-kw. Turbine-generator in the Long Beach Station of the Southern California Edison Co.

There are now installed or under construction a total of 28 G-E turbines designed for steam pressures of 550 lb. and higher with an aggregate capacity of about 1,500,000 kw.

The rapid increase in the adoption of 1200-lb. pressure (Fig. 2) is indicated by the growth in capacity since 1923, when a 3000-kw. unit was first utilized. By the end of 1927, four units had been contracted for aggregating 27,000 kw., and during 1928 five additional units designed for 1200-lb. steam pressure with a total capacity of 186,000 kw. were completed or under construction.

The main turbines of the Deepwater Station, an all-high-pressure installation which is owned jointly by the American Gas and Electric Company and the

American Electric Power Corporation, Stevens and Wood engineers, are two 53,000-kw. cross-compound units each consisting of an 1800-r.p.m. low-pressure element and a 3600-r.p.m. high-pressure element. A third high-pressure turbine, a duplicate of the other two, will exhaust into an evaporator and furnish process steam for a nearby factory.

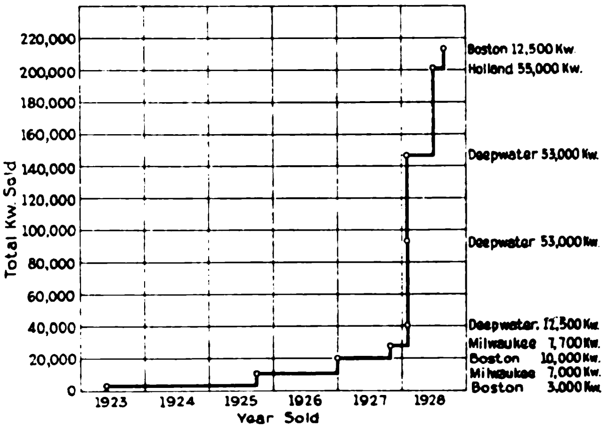

Fig. 2. Growth in the Use of 1200-lb. Steam Pressure with G-E Turbines

These high-pressure turbines have multi-valve control applied for the first time on 1200-lb. machines to secure a flat load curve.

Another station to be designed for 1200 lb. exclusively will be built by the W. S. Barstow Company, Inc., Holland (N. J.), The turbine is to be a 55,000-kw. cross-compound unit similar in all respects to the Deepwater machines.

The Edison Electric Illuminating Company of Boston is adding a third 1200-lb. turbine of 12,500-kw. capacity. In order to obtain improved economy at light loads and better overall station efficiency, this turbine which has multi-valve admission was selected rather than a duplicate of the present single-valve 10,000-kw. unit which, together with a 3000-kw. unit, was previously installed in this station. The new unit is similar to the high-pressure elements of the Deepwater and Holland turbines.

Single-cylinder

The 75,000-kw. 1500-r.p.m. single-casing machine of the Buffalo General Electric Company is in commercial service and is the largest 25-cycle single-casing turbine-generator.

During the year the maximum size of 1800-r.p.m. single-cylinder turbines increased 10,000 kw. to give a total of 75,000 kw. A unit of this size is being built for the Union Electric Light and Power Company for installation in the Cahokia Station at St. Louis. The steam conditions are 315 lb., 725 deg. F.

Tandem-compound

A 94,000-kw. unit, the largest tandem-compound turbine in the world (Figs. 1 and 3), is now operating in the Long Beach Plant of the Southern California Edison Company and a duplicate machine is being constructed.

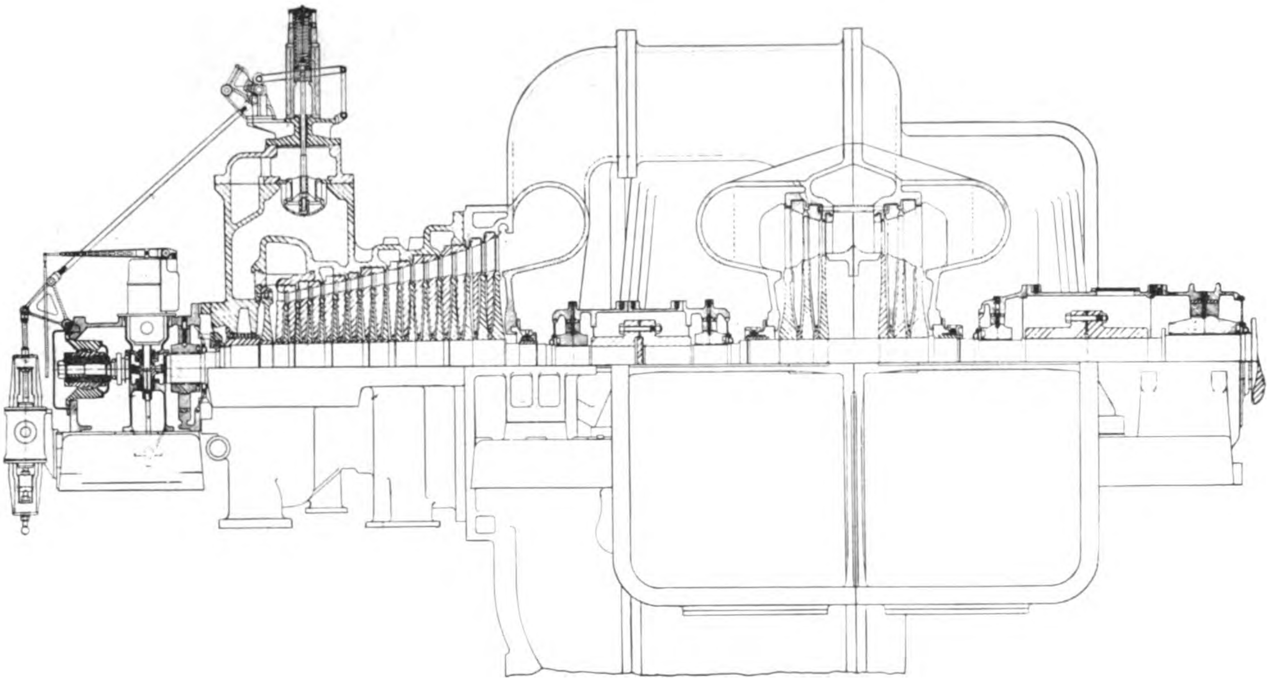

Fig. 3. Sectional Drawing of 94,000-kw. 1500-r.p.m. 21-stage Turbine

The 94,000-kw. units will be exceeded in size by the completion of a 160,000-kw. 1500-r.p.m. tandem-compound turbine-generator for the New York Edison Company.

The installation of the two 52,500-kw. tandem-compound turbines for the Societie Financiere de Transports at Buenos Aires was completed. They are designed for 550-lb. steam pressure and operate on the reheating regenerative cycle. This is the first development of this kind outside of the United States.

Cross-compound

A 165,000-kw. triple cross-compound unit is now in commercial service in the Philo Station of the Ohio Power Company. The steam conditions are 600 lb., 725 deg. F. with reheat in the boilers to 725 deg. F. between the high and the two low-pressure elements.

On large multi-valve machines of this type it is now the practice to add a device to the governor mechanism which "hooks up" the linkages so that in starting all the valves, except the primary valve, are kept closed. This reduces the demand for steam from the boilers and assures a more uniform warming up. Formerly, with all the valves open the first steam admitted by-passed the first stages and ineffectively drifted through the large overload passageways.

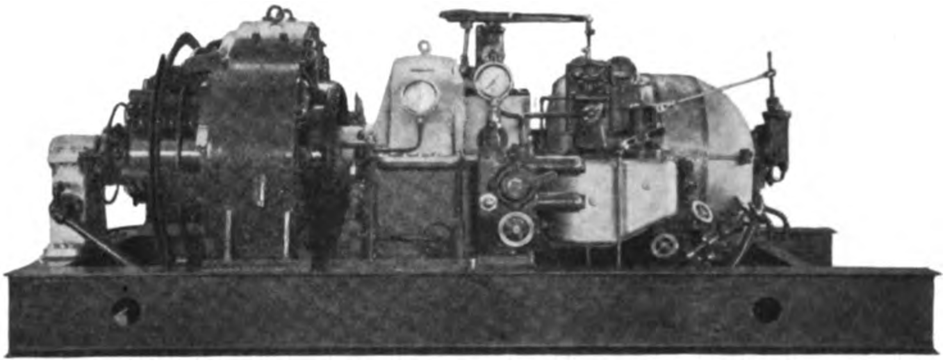

Fig. 4. A 250-kw. 10,000-r.p.m. Auxiliary Turbine-generator for Installation on U. S. Scout Cruiser

The 208,000-kw. triple cross-compound unit for the State Line Generating Company was shipped to be placed in operation in 1929.

Generators

There was a notable increase in the voltage of generators for turbine sets.

The first 16,500-volt generator was placed in operation in the Long Beach Station of the Southern California Edison Company. It is rated 100,000 kv-a., 50 cycles, 1500 r p.m.; and in spite of its exceptional size and weight, the stator which has a frame of welded construction was assembled, wound, tested, and shipped as a complete unit.

The Super Power Company of Illinois at Pekin has one unit installed and a duplicate under construction with generators wound for 22,000 volts, rated 61,765 kv-a., 1800 r.p.m.

The generators for the 208,000-kw. triple cross-compound set for the State Line Generating Company are also wound for 22,000 volts. The high-pressure turbine drives the largest of the three generators which is rated 76,000 kw., 89,411 kv-a., 1800 r.p.m. The two low-pressure generators are rated 62,000 kw. each.

A single generator having a double winding and a total capacity of 160,000 kw. is being built for the New York Edison Company. It is the largest and highest rated generator so far constructed.

INDUSTRIAL TYPE TURBINES

There was a wide diversity of application in the industrial field, also an increasing demand for greater refinement particularly in governing and speed control. There was furthermore a trend toward higher steam pressures and temperatures, and a marked increase in the number of units provided with automatic extraction from one or more points.

A turbine of 2500-kw. capacity was especially designed for quick starting in cases of emergency. By actual test this unit was started from a cold condition, brought up to speed with full field, and ready for load in 12 sec. By means of remote control the unit may be started and stopped from a distant station. At times the turbine will float on the line as a synchronous condenser with the steam inlet valve closed and vacuum in the casing. With a drop in frequency below normal, the steam inlet valve is opened and the unit reverts to speed governing and non-condensing operation automatically. The operating steam conditions are 400 lb. gauge, 700 deg. F., and 3 lb. gauge back pressure.

Two 5000-kw. turbines operating at 375 lb. gauge, 692 deg. F. and 2 in. absolute back pressure are arranged for reducing-valve extraction of variable demand from zero to 12,000 lb. per hr. at 50 lb. gauge and for full automatic extraction in varying quantities from zero to 72,000 lb. per hr. at 20 lb. gauge. They are repuired to operate in parallel, and divide both the electrical load and the extraction. These machines operate perfectly in parallel either with or without extraction and with a relative speed change as low as 1.3 per cent.

For water-works service, a 2515-hp. turbine will operate at a constant speed of 3600 r.p.m. and will drive, in addition to a 1000-kw. 60-cycle 4000-volt alternator, a high-head centrifugal pump through a 905-hp. reduction gear operating at 1140 r.p.m. on the low-speed shaft.

The twenty-four 250-kw. d-c. geared turbine sets (Fig. 4) for installation on scout cruisers operate at 10,000 r.p.m. with steam conditions of 275 lb. gauge dry and 28 in. vacuum, and drive through a single-reduction gear a direct-current generator operating at 1200 r.p.m. They were especially designed because the weight, economy, and overall dimensions were of prime importance. The turbine, gear, and generator are mounted on a fabricated I-beam base.

A variable-speed turbine and gear (Fig. 5) were built for paper-mill service. The low-speed end of the gear is connected through sheave pulleys to the paper mill and the exhaust steam from the turbine is used in the dryers. Speed control can be held within very narrow limits at any point between 65 r.p.m. and 390 r.p.m. on the driven shaft. The unit is rated 475 hp. at 4200 r.p.m. and operates at 110 lb. gauge steam pressure, 470 deg. F., and varying back pressures between 20 and 40 lb. gauge.

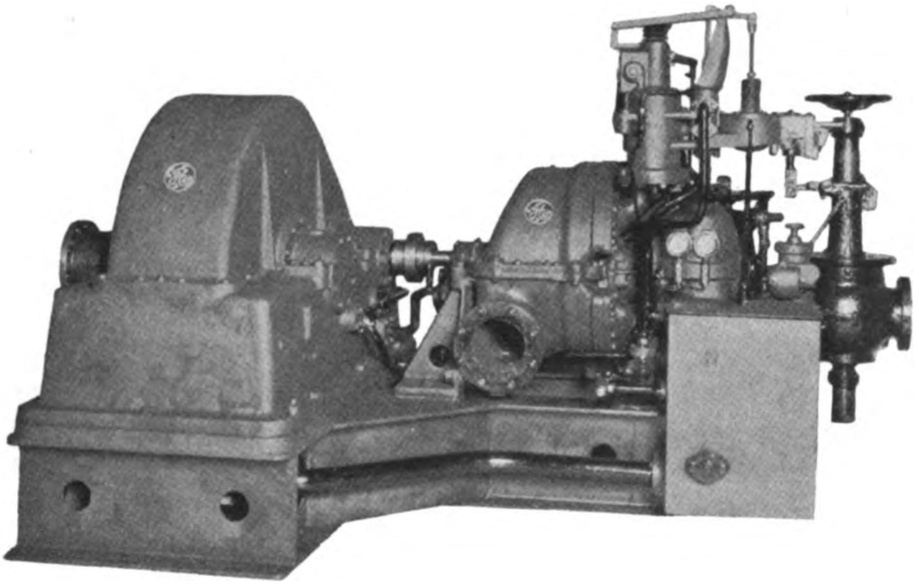

Fig. 5. Variable-speed Turbine with Reduction Gear for Paper-mill Service

A 7500-kw. 3600-r.p.m. turbine was put in service for driving paper machines and is the largest industrial turbine for paper-mill drive in this country. The operating conditions are 190 lb. gauge, 650 deg. F., 2 in. absolute back pressure, and the turbine is arranged for full-automatic steam extraction at 10 lb. gauge.

There was under construction for a steel company a 5000-kw. 3600-r.p.m. non-condensing turbine to handle under full-load conditions upwards of 283,000 lb. of steam per hour and approximately 372,000 lb. per hour under overload. The operating conditions are 350 lb. gauge, 636 deg. F., 150 lb. gauge back pressure. The unit will be so built as to have a very flat load curve.

EMMET MERCURY VAPOR PROCESS

The mercury vapor power plant equipment (Fig. 6) installed in the South Meadow Station at Hartford (Conn.), was put into commercial service during October, 1928, and operated in the most satisfactory manner.

The first runs made have indicated the desirability of certain modifications that will require some few weeks, and meanwhile it should be appreciated that no fundamental changes are involved, but merely minor adjustments. The data taken from the log sheets(1) were highly gratifying.

Table I(2) gives data on the designed conditions of the equipment.

Preliminary results obtained to date indicate that the fuel economy of the process is rather better than these predicted results because of a high mercury-turbine efficiency. It is expected to make public the operating data at an early date.

Pulverized coal is burned under the mercury boiler (Fig. 7), being supplied from three pulverizing units installed on the firing floor. Heated air is supplied to the furnace after passing first through an air preheater and then through cast-iron ducts in the furnace walls. The radiant-heat-absorbing properties of the mercury boiler insure a relatively cool furnace. When operating at full load, a small amount

TABLE I

Output of mercury turbine	10,000 kw.
Speed of mercury turbine	720 r.p.m.
Steam produced per hour	125,000 lb.
Steam pressure	350 lb. gauge
Steam temperature	700 deg. F.
Mercury vaporized per hour	1,150,000 lb.
Temperature mercury vapor	884 deg. F.
Pressure vapor at mercury turbine	70 lb. gauge
Vacuum in mercury condenser	28 in.
Temperature mercury exhaust	458 deg. F.
Gas temp. beyond mercury liquid heater	950 deg. F.
Gas temp. beyond steam superheater	650 deg. F.
Gas temp. beyond water economizer	480 deg. F.
Gas temp. to stack	280 deg. F.
Air temp. entering furnace	390 deg. F.
Coal burned per hour	14,500 lb.
Heat in coal per pound	14,500 B.t.u.

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(1) See *Electrical World*, Nov. 17, 1928, p. 1007.

(2) From "Economies of the Emmet Mercury Process," by W. L. R. Emmet, GENERAL ELECTRIC REVIEW, July, 1927, p. 339.

of slag collects on the extreme ends of the mercury-boiler tubes but none on the sides of the tubes. This slag collects slowly and needs to be blown off only once a shift. These results are obtained with a high CO_2 content of the flue gases. The mercury turbine, which is installed on the floor above the boiler, operates at full speed with entire absence of vibration and the noise is so slight that it is difficult to detect by the sound when the turbine is running. The mercury condensers operate perfectly, a good vacuum being easily maintained at all loads.

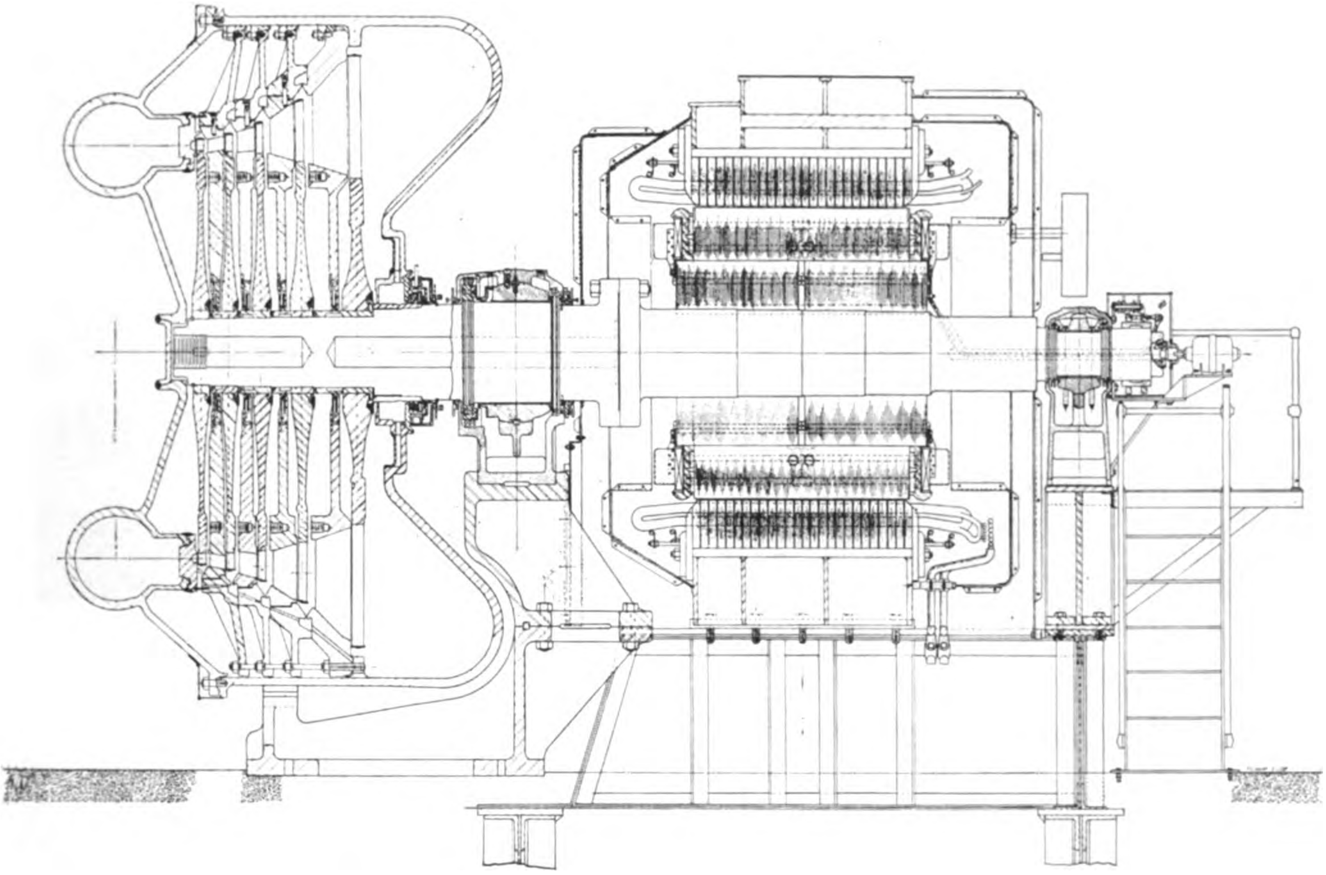

Fig. 6. Sectional View of 10,000-kw. Mercury Turbine

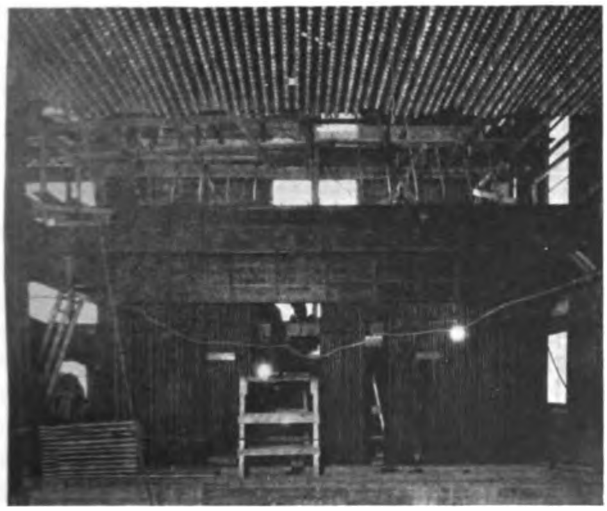

Fig. 7. Mercury Boiler During Construction

MARINE EQUIPMENT

The outstanding events in the marine field were the launching of the second of the three electrically-propelled passenger liners for the Panama-Pacific Line of the International Mercantile Marine Company, and an increase in the amount of power applied to a single propeller shaft on a Diesel-electric ship.

Electric drive was adopted for three new types of ships during the year; the tunnel-stern propeller-type of towboat, the packet boat, and the lightship.

Turbine Electric

On August 18th, the passenger liner *Virginia* (Fig. 8) was launched and was in active service at the close of the year. This craft is somewhat larger than the *California*, which has now been in service for a year; and work on the propelling equipment for a third ship of this class is now under way. All three of these ships are of the twin-screw type with a displacement exceeding 30,000 tons at load draft and develop a speed of 16½ to 18 knots with a maximum power development of 17,000 s.hp. The propeller shafts are, in each case, direct driven by an 8500-hp. reversible-type motor.

The *Viceroy of India*, a 19,000-ton turbine-electric passenger liner, was built in England for the Peninsula and Oriental Navigation Company for service between the ports of England, India, and Australia.

This is the first large electrically-driven ship ever built in England and the main electric propelling equipment was constructed by the British Thomson-Houston Company. The ship is 600 ft. long and the power plant comprises two turbine-driven generators either of which, when working alone, is capable of driving the ship at 16½ knots, the maximum speed being 19 knots.

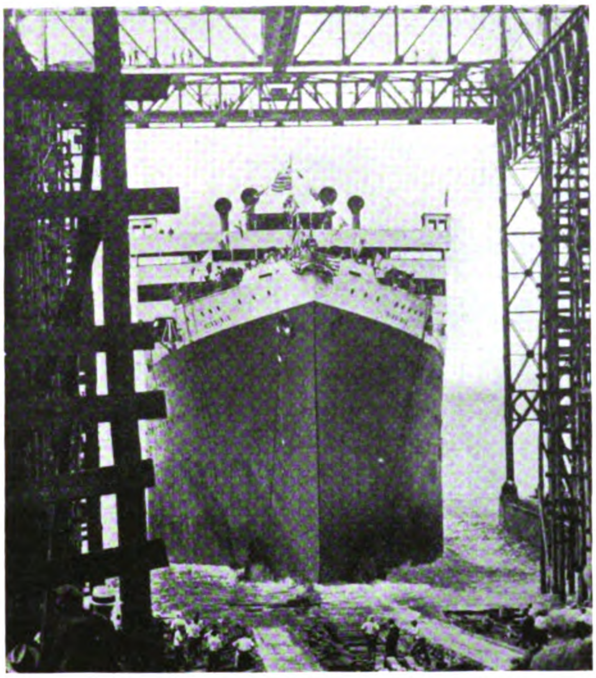

Fig. 8. Launching of the International Mercantile Marine Liner *Virginia*

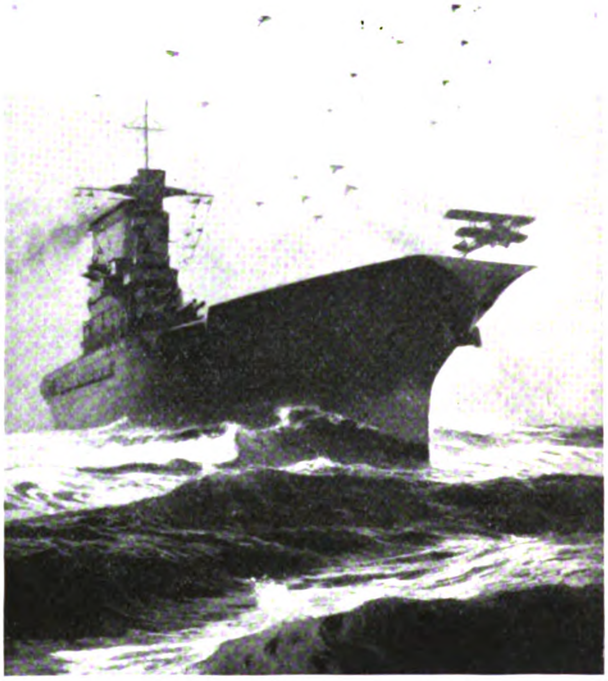

Fig. 9. U.S.S. *Saratoga* with Electric Propelling Equipment of 180,000-shaft Horsepower

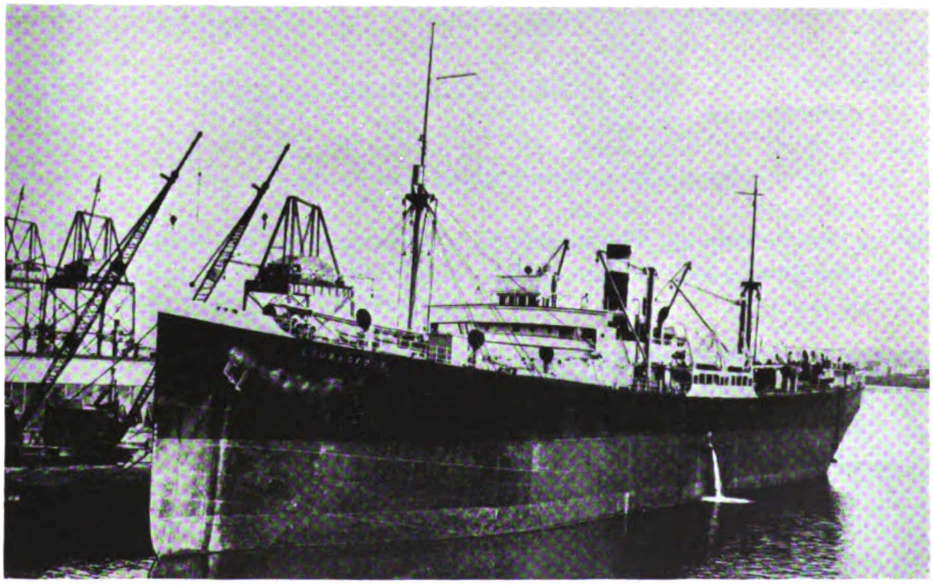

Fig. 10. Motorship *Courageous* with Single Propeller Driven by a 4000-s.hp. Motor

The airplane carriers *Saratoga* and *Lexington* underwent their sea trials and broke all existing speed records for capital naval ships. The *Saratoga* (Fig. 9) maintained a speed of 33.42 knots over a measured mile course, while the *Lexington* averaged 30.7 knots for 72 hours between San Pedro (Calif.) and Honolulu, a distance of 2228 nautical miles. On the acceptance trials run in November, the *Lexington* developed 210,000 hp. and a speed of 34.62 knots.

For the year 1927-28, the battleship *New Mexico*, the first electrically-propelled capital ship in our navy, was for the second time awarded the battle efficiency pennant, the previous award being for the year 1920-21. It is interesting to note that, during the past eight years, the winners of this pennant have, with a single exception, been electrically-propelled ships.

Diesel Electric

The most outstanding installation was that for the motorship *Courageous* (Fig. 10), a converted freight vessel owned by the U. S. Shipping Board. This craft was formerly turbine-gear driven with equipment having a power rating of 3000 s.hp., and was reëngined with a Diesel-electric power plant of 4000 s.hp. which is the highest rating for a single-propeller Diesel-electric drive. This change, in combination with modified propeller speed and structural alterations, resulted in increasing the ship speed from 10½ to more than 13 knots. The new drive, in spite of its increased power, occupies less space and is lighter than the original equipment.

The main power plant consists of four Diesel-engine-driven d-c. generators, each rated 800 kw., 250 r.p.m., 385 volts. On the end of each main generator shaft an auxiliary d-c. generator of 100 kw. capacity is connected for furnishing power for excitation and for the ship's auxiliaries and lights. The main propelling motor (Fig. 11) which is directly connected to a single propeller shaft is of the double-motor type and rated 4000 s.hp., 60 r.p.m., 1500 volts.

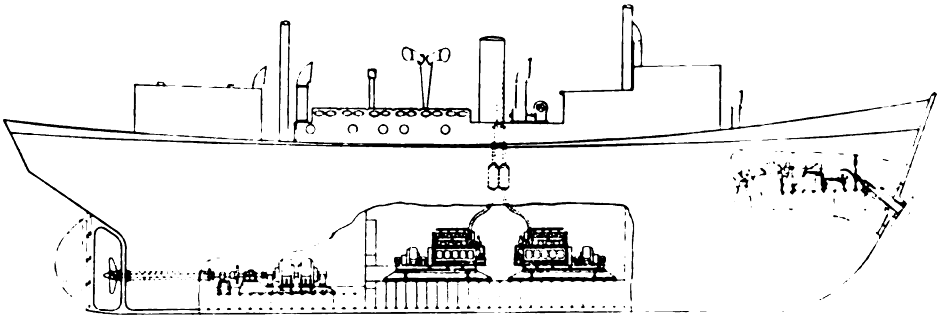
Fig. 12. Arrangement of Diesel-electric Machinery on Lightship

The control is of the variable-voltage type, and when operating at maximum power the armatures of the four main generators and the propelling motor are connected in series. For reduced speed, one or more of the generators may be cut out of the line.

Pilot-house and engine-room control permits the ship to be maneuvered either entirely from the bridge or from the engine room as desired. Both the deck and underdeck auxiliaries are completely electrified. The deck auxiliaries consist of twelve cargo winches with the latest type of automatic control, one warping winch, and one anchor windlass.

The underdeck auxiliaries consist of the steering gear, refrigerating plant, ship's ventilating fans, and pumps for the following purposes: bilge, ballast, fire, sanitary, fuel-oil transfer, fresh water, lubricating oil, and circulating water. Miscellaneous motors are employed for the oil purifiers, machine shops, etc.

Three lightships, operated by the Bureau of Lighthouse Service, were provided with Diesel-electric drive (Fig. 12). They are the first of their type to be so equipped. Heretofore, lightships have been powered with steam propelling equipment for use in navigating between their station and home port, and to drive ahead against a storm in order not to drag anchor. Diesel-electric drive, on account of its low fuel consumption, permits a much longer stay at the stations and also gives an immediate reserve of power for use in emergencies. Power from the main generating set is also used to operate the very powerful anchor windlass equipments installed on these ships.

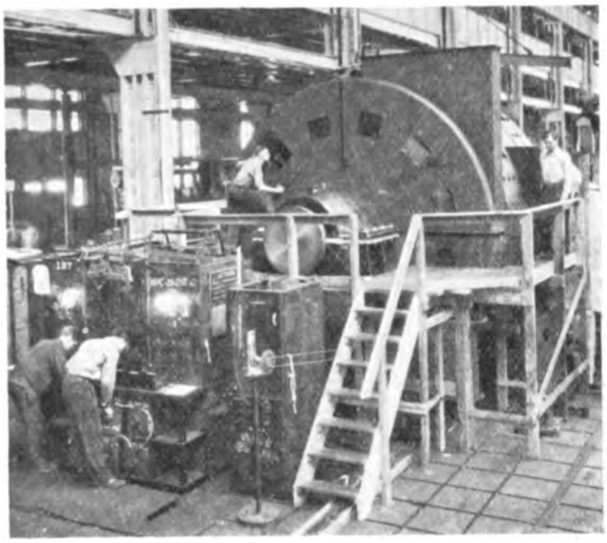
Fig. 11. Testing 4000-s.hp. D-c. Propulsion Motor for Motorship *Courageous*

Fig. 13. Diesel-electric-driven Packet Boat *Edward Farrington*

The equipment for each lightship consists of four 75-kw. main generators, and two 7½-kw. separately-driven auxiliary generators, the single propelling motor being rated 350 s.hp. at 300 r.p.m.

The Diesel-electric-driven packet and freight boat, the *Edward Farrington* (Fig. 13), operated by the Middlesex Transportation Company, is a good example of how electrification can be used to meet the specific needs of our domestic merchant marine. This small craft which has an overall length of 132½ ft., is propelled by a 400-hp. motor that gives a speed of 12 knots. The boat is called upon to navigate congested harbors and therefore the use of the pilot-house system of control is of unusual value. All the auxiliaries are completely electrified and the boat is provided with an electric hoist which is also operated from the bridge.

There was an extension in the field of application of Diesel-electric drive on river towboats of the propeller type. Two such boats were built for use in transporting steel products along the Warrior River in Alabama, for the Tennessee Coal, Iron and Railroad Company of Birmingham (Ala.). The new boats are of the tunnel-stern twin-screw type. The main power plant consists of two Diesel-electric-driven direct-current generators, each rated 335 kw., 250 volts, 250 r.p.m. The main propelling motors which are directly connected to the propeller shafts are of the double type and each is rated 400 hp. at 140 r.p.m. Power for the auxiliaries and lighting, as well as for the excitation of the main generator and propelling motors, is furnished by two 40-kw. 120-volt d-c. auxiliary generators which are driven directly from the main-generator shaft.

Electric drive was adopted for these boats in order to obtain higher efficiency and better maneuvering properties, as the river in which they are used is swift, shallow, and tortuous. The boats may be operated either from the bridge or the engine room as desired.

The Norfolk County Ferries of Portsmouth (Va.), selected Diesel-electric drive for their new automobile and passenger ferryboat, which is to ply between Portsmouth and Norfolk. The power plant consists of two Diesel-engine-driven direct-current generators each rated 270 kw. and a propelling motor of the double-motor type rated 670 s.hp.

The combination harbor and sea tugs *Trinidad* and *Chagres* (Fig. 14), which are the highest-powered Diesel-electric-driven tugs in the world, were placed in service. They are owned and operated by the Panama Canal, have a capacity of 108 tons of Diesel fuel oil which is sufficient for a cruise of 25 days, and have a range of approximately 7000 miles. They may thus be used in case of emergency for servicing or towing disabled ships at sea. They are equipped with a 500-watt radio set having a range of 1000 miles, for use when engaging in sea service.

These tugs can also be used for fire fighting as they are equipped with 1000-g.p.m. pumps at 100 lb. pressure. In ordinary service around the Canal Zone, they are utilized for towing barges from the dredges to the dumping grounds and for assisting vessels through the locks.

The auxiliary equipment is electrified throughout and consists of a combination capstan and anchor windlass, automatic towing machine with inhaul capacity of 75 ft. per min. at 25,000 lb., electric steering gear, electric refrigeration, and motor-driven pumps, compressors, and ventilating fans in the engine room.

The main propelling motors are of the double-motor type, built to deliver continuously 900 s.hp. at 1450 amp. and 500 volts. The operating range at full power is 115/150 r.p.m.

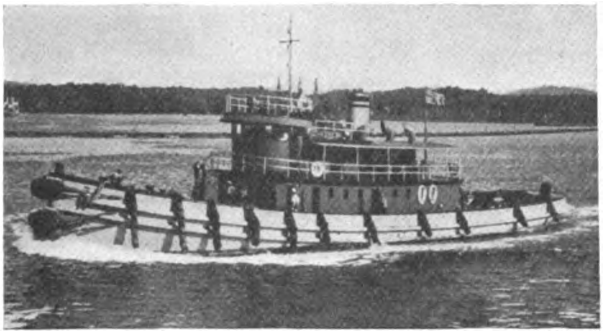

Fig. 14. Panama Canal Commission Tug *Chagres*

Italy is to have its first Diesel-electric-driven vessel. The Compagnia Generale di Elettricita of Italy will build the generators and propelling motors for a 4500-s.hp. twin-screw railroad car and automobile ferry for the Italian Government Railways. This ferry is to operate across the Straits of Messina between Messina and Reggio. The control equipment will be built in the United States.

The main power plant will consist of three Diesel engines, each of which drives two direct-current generators. The motors, which are directly connected to the propeller shafts, are of the double type.

ELECTRIC RAILWAYS

Among authorities in the street-railway industry there is a feeling that, in spite of the readjustment which has been going on for some years, there is still a very general tendency toward the improvement of street-railway properties, more particularly in the larger cities where there exists a definite demand for local and interurban transportation.

That this demand is not confined to the larger cities requiring mass transportation is indicated by the experience of the city of Phoenix (Ariz.), with 26,000 population. It was determined some little time ago that the city could not do without the electric railway; and the municipal authorities, therefore, took over the operation. In order to modernize the system and furnish desirable service, the city authorities replaced some of the existing equipment with 18 new light-weight cars, each provided with four 25-hp. motors and platform-type control.

Another important modernization program was completed by the Kansas City Public Service Company by the installation of modern control on 91 existing cars (Fig. 15). The Dallas Railway and Terminal Company placed in service 17 new light-weight cars, each with four 35-hp. motors and platform-type control. Five similar equipments were placed in service by the Delaware Electric Power Company at Wilmington (Del.).

An interurban property, the Indianapolis and Southeastern Railway, added ten new double-truck motor cars, each provided with four 40-hp. motors and complete modern air-brake equipment. One hundred straight-air-brake sets and five motor and control equipments were adopted for new cars on the Cincinnati Street Railway system.

The Community Traction Company of Toledo recently instituted a program of changing from two-motor to four-motor operation in order to speed up schedules. For this change the company is using 120 35-hp. motors and new control.

New rolling stock for the Interborough Rapid Transit Lines in New York includes 30 cars, each with two 120-hp. motors and electro-pneumatic control. New motor cars for electrified steam lines included ten additional cars for the Illinois Central suburban electrification at Chicago, duplicates of the original cars which utilized four 250-hp. motors per car with electro-pneumatic control. The New York Central Railroad for its New York Terminal added ten cars each equipped with two 200-hp. motors and electro-pneumatic control. This company is now operating a total of nearly 350 G-E equipped motor cars in its suburban service.

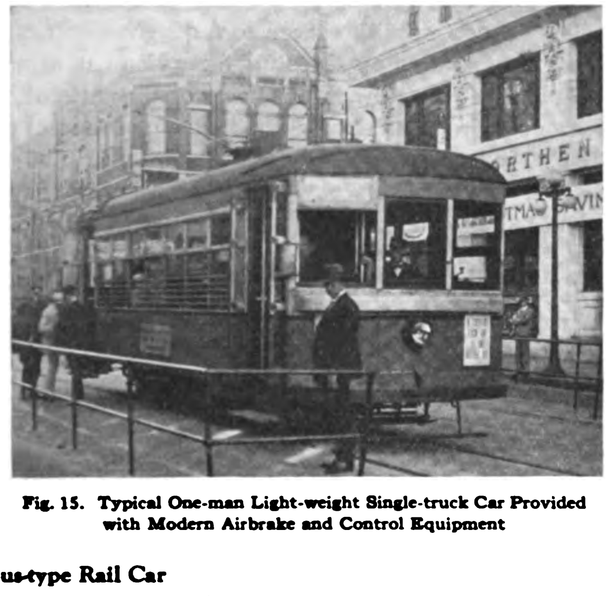

Fig. 15. Typical One-man Light-weight Single-truck Car Provided with Modern Airbrake and Control Equipment

Bus-type Rail Car

A new design of light-weight trolley car, built by the Twin Coach Company, has a bus-type body with flanged wheels substituted for rubber tires. Equipment designed for this type of car consists of four automotive-type motors with double-reduction gear. The car has a total weight of 16,000 lb.

Interesting devices include an edgewise wound-resistor (Fig. 16) suitable for locomotives, motor cars, or trolley buses. In addition to a considerable reduction in weight, the resistor is practically unbreakable and has other attractive features such as the use of non-corrosive metal and provision for numerous taps, thereby permitting a variety of resistance values. The development of an entirely new resistance material, having a high tensile strength and a temperature coefficient of resistance approximately one-quarter that of cast iron, contributed greatly to the success of this resistor.

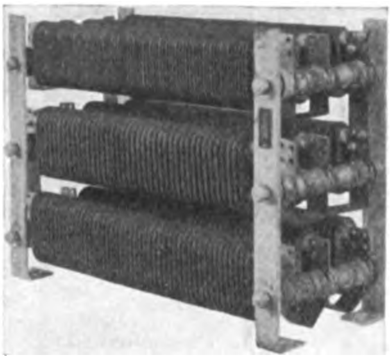

Fig. 16. New Type of Edgewise-wound Railway-control Resistor

A new type of control for street cars and trolley buses was introduced which is of particular interest in that it makes use, in a novel manner, of a relatively few cam-operated units to obtain a large number of accelerating points. The arrangement permits the construction of a controller having 18 points with a relatively small number of parts. The operation is automatic under the control of an acceleration relay.

In addition to the advantages of automatic operation, this type of control by virtue of its many contact points permits an average rate of accelerating approximately 20 per cent greater than that obtained with standard types when exerting the same maximum tractive effort at the rims of the wheels. Where the slipping point of the wheels is not the limiting factor, a 75 to 100 per cent increase in acceleration can be used without discomfort to the passengers. Acceleration rates of 3½ to 4 miles per hour per second can be obtained, thereby permitting the operation of modern light-weight trolley cars or trolley buses at a rate comparable or even exceeding that of other traffic.

This type also permits foot control by the operator; a modern tendency in the operation of light-weight cars and trolley buses.

A new 50-cu. ft. center-gear-type air compressor was developed, particularly for service on oil-electric locomotives; the motor being designed for operation from the 125-volt circuit supplied by the exciter.

A replica-type thermal relay was applied to some types of railway motors. It is designed to have the same characteristics as the motor to which it is applied, *i.e.*, the copper loss, core loss and blown cooling characteristics are the same as that of the motor.

In addition to contacts which open the control circuits, in the event of excessive temperatures, indicators are provided at the motorman's operating position. The new temperature indicator is practically independent of the voltage supply, which is an important feature for locomotive applications.

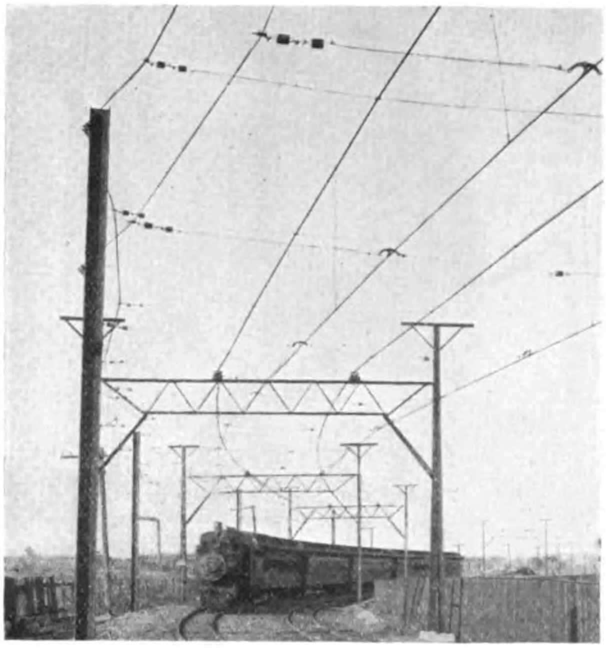

Fig. 17. View on Line of Boston, Revere Beach and Lynn Railroad, Showing Steam Locomotive and Overhead Construction for Subsequent Electrical Operation

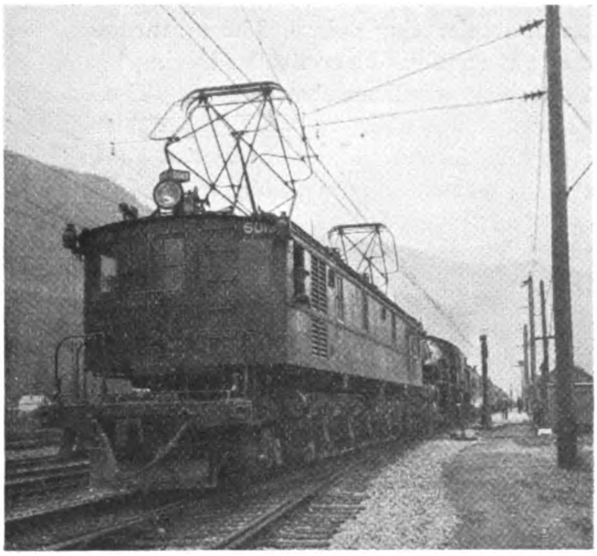

Fig. 18. 260-ton, A-c.-D-c. Locomotive in Service on the Great Northern Railway

The application of this type of relay and indicator permits more intelligent use of the full capacity of the motors, at the same time protecting against excessive temperatures.

Trolley Buses

After an extended demonstration with a trolley bus, the Manila Electric Company placed in service during the year eight similar equipments in the city of Manila. Trolley buses have been in service for a number of years on the lines of the United Traction Company in Cohoes (N. Y.) and by the Rochester lines of the New York State Railways. Experience gained on this line indicates advantages in operation and cost of maintaining equipment.

Reduction Gears

A worm drive for use with light-weight 35 and 50-hp. motors was tried out on several installations in Montreal, Detroit, Boston, St. Louis, Dallas, and Cincinnati. Eight 50-hp. double-reduction drives were applied on a two-car train in Chicago for trial operation. The advantages or disadvantages of this type of equipment should, therefore, be fully demonstrated during 1929.

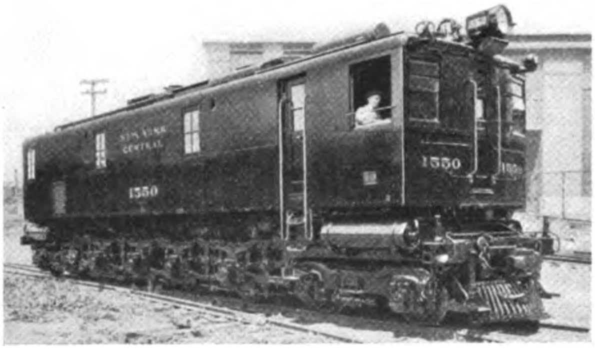

Fig. 19. 750-hp. Oil-electric Freight Locomotive

Gas-electric Buses

The most notable extension of gas-electric bus service was made by the Public Service Coördinated Transport for use in various parts of the state of New Jersey. Three hundred and thirty-one buses were placed in service, making a total of over 800 gas-electric-driven buses now operated by this corporation. Other applications of electric transmission to buses were made by the city of Detroit with 25 units; the Boston Elevated Railway with 38; the International Bus Company of Buffalo with 10; the Capitol District Transportation, Albany and Troy, with 7; and the United Railways of Providence, and the Montreal Tramways with 2 each.

A new brake-control valve for this service is applied by the movement of the brake pedal commonly used on gasoline vehicles, and is so adjusted that the pressure of air admitted to the cylinder varies in accordance with the position of the brake pedal.

Steam-road Electrification

The most important railroad electrification initiated during the year was the Cleveland Union Terminals project. Plans for this development have been under way for several years and the new terminal building, 54 stories in height, is nearing completion. Seventeen route miles are involved and 3000 volts direct current will be used with overhead catenary supply.

There are now under construction twenty-five 204-ton passenger locomotives rating approximately 3000 hp. each which will be required for handling passenger trains of the New York Central and other roads in and out of this terminal. The design of this locomotive includes two three-axle driving trucks with six twin-geared motors and a two-axle guiding truck at each end of the unit. These locomotives will be capable of handling trains weighing 1275 tons over the electric zone at an unusually high schedule speed.

Two substations will be used for direct-current power supply, one containing three 3000-kw. synchronous motor-generator sets and the other two similar sets. Power will be purchased from the local power company. While the work being done at present is strictly a terminal electrification, the system selected will permit of future extensions at the same voltage on the main line of the New York Central.

An important decision was made recently regarding the selection of a system by the Delaware, Lackawanna and Western Railway. This company has announced that the 3000-volt system will be used for the electrification of the Hoboken Terminal and suburban zone, for which equipment will be specified during 1929. The selection of this system will allow the extension of the electric zone over the main line to Scranton (Pa.) without change of voltage.

Another notable electrification was completed during the year by the so-called "Narrow-Gauge," the Boston, Revere Beach and Lynn Railroad. This road has been an important passenger line for many years (Fig. 17) and was electrified to improve the equipment, make faster schedules, and thus further increase the possible business. The steam locomotives were replaced by electric motor cars operated in trains of two to eight cars each. The existing passenger coaches were provided with motor and control equipment, new lighting and heating, and are now modern in every respect. Sixty cars have been so equipped.

Three substations were provided; one at Orient Heights near Boston, the second at Lynn, and the third a portable station. They are supplied from the local power systems at Lynn and Boston. The Orient Heights station is completely automatic and the other two are manually controlled. The overhead construction is of the catenary type for 600 volts direct current using steel bridges throughout.

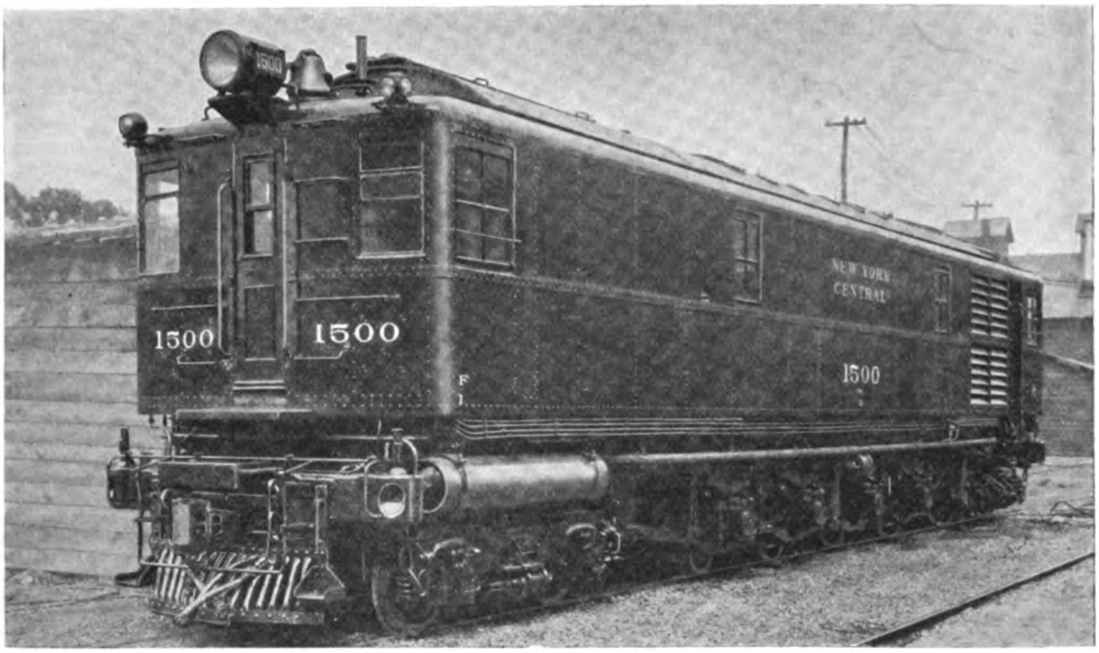

Fig. 20. 900-hp. Oil-electric Passenger Locomotive

Delivery of additional passenger locomotives to the Paulista Railway in Brazil brought the total number of the 150-ton type up to five units and the total number of all G-E locomotives to 26 units. Two 260-ton locomotives (Fig. 18), of similar construction to those originally installed, were placed in service by the Great Northern Railway on the electric zone through the Cascades. Operation through the new 7¾-mile Cascade tunnel was expected to begin about the end of the year.

Two 150-ton 3000-volt direct-current locomotives are under construction for the Mexican Railway to take care of additional motive power requirements for the extended electric zone. Both locomotive and car equipment were also installed on the Pennsylvania Railroad, including motors and control for four 200-ton locomotives built by the railroad company for operation on the New York Terminal and thirty single-phase motor-car equipments for the new Wilmington and Westchester Division.

Other apparatus for this electrification includes a number of air-break high-speed circuit breakers for use on 12,000-volt 1500-amp. single-phase feeders. This is the first commercial alternating-current air-break circuit breaker to be designed for so high a voltage. It is capable of opening a short circuit on 25 cycles in one-half cycle and has a rated rupturing capacity of over 30,000 root-mean-square amperes. Because of the high speed of circuit interruption, this device is valuable in the reduction of inductive interference with communication and signal circuits.

Oil-electric Locomotives

A total of thirteen oil-electric locomotives (Figs. 19 and 20) were completed or under construction during the year. They include a number for industrial service, such as those for the Donner Steel Company which is using four 60-ton units each equipped with a 300-hp. engine, the American Rolling Mills Company's 100-ton unit equipped with two 300-hp. engines, and three 74-ton units each equipped with one 300-hp. engine.

The Reading Company added a 60-ton 300-hp. locomotive, the Erie Railroad a similar unit, and the Hoboken Terminal Railroad both a 74-ton 300-hp. and a 110-ton 600-hp. locomotive. The Illinois Central Railroad placed in service a 100-ton 600-hp. locomotive in its switching yards in Chicago.

Gas-electric Motor Cars

The thorough appreciation of the advantages of the gas-electric motor car for branch-line steam roads is indicated by a total of 117 cars placed in such service during the year. Some of the larger installations were made by the Pennsylvania Railroad, 14 cars; the Chicago and Northwestern, 28 cars; the Frisco System, 7 cars; the Chicago, Rock Island and Pacific, 14 cars; the Missouri Pacific, 4 cars; and the Chicago, Burlington and Quincy, 29 cars. These cars (Fig. 21) vary somewhat in weight and power ranging from 200 to 800 hp. in one, two, or three-unit power plants.

The self-propelled equipment of the Chicago, Rock Island and Pacific Railway and the Union Pacific is especially notable on account of the successful use of distillate fuel in place of the usual gasoline, and because of the unusually high power of some of the cars now in service. Several Rock Island units used in branch-line work carry two 400-hp. engines. This permits the car to be used for either passenger or light freight work, eliminating steam equipment entirely from some of the branch lines.

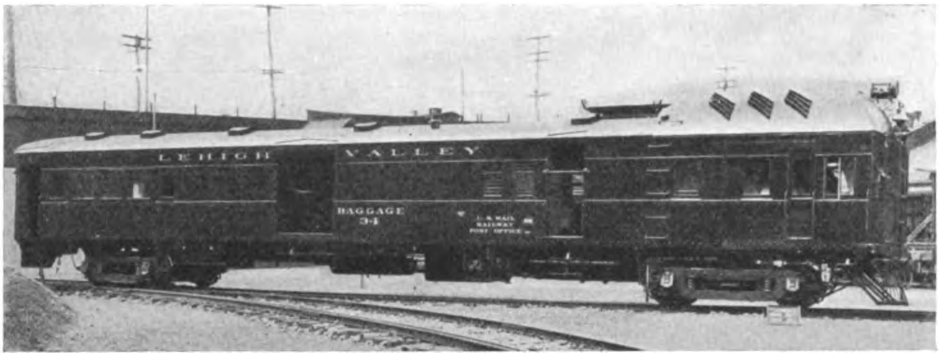

Fig. 21. Gas-electric Motor Car Equipped with Two 290-hp. Engine-driven Generating Sets

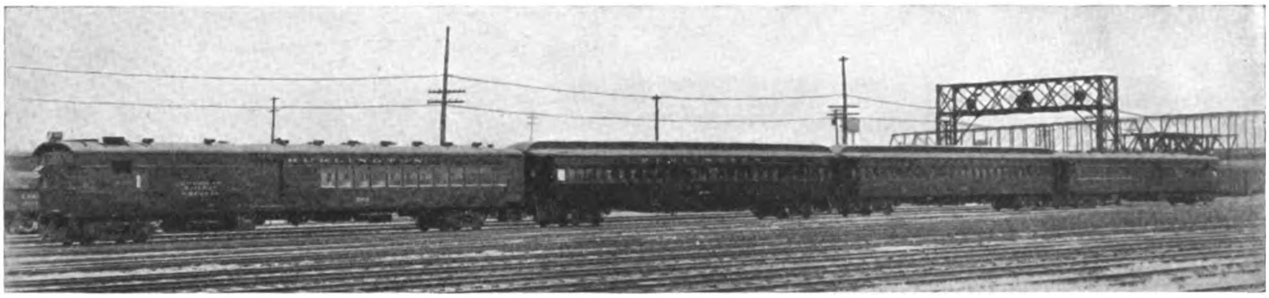

Fig. 22. Train Used in Dual-control Demonstration of Gas-electric Cars

An interesting demonstration was made on October 2nd by the Chicago, Burlington and Quincy Railway, of a gas-electric car train. The equipment used (Fig. 22) consisted of a dual-power-plant 270-hp. car used at one end of the train, and a triple-power-plant 405-hp. demonstrator car with two standard day coaches between, making a total train weight of about 230 tons. Temporary electrical connections between the two motor cars permitted operation of the train by a single engineman in the cab of the 72-ton triple-power-plant car on the outbound trip. On the return trip without any change in arrangement, the train was operated from the dual-power-plant car at the opposite end of the train and in the reverse direction. During the 21-mile trip outbound, stops were made at the rate of one per mile and on the return trip the train was run express.

Radio Train Communication

Radio equipment for communication between the front and rear ends of long freight trains, which had been previously tried out by the New York Central, was installed by the Baltimore and Ohio Railroad for demonstration on that system.

An unique application of radio to locomotive operation is being tried out by the American Rolling Mills Company at Ashland (Ky.). The sets being used are similar to those used on main-line freight trains, but in this case one unit is installed in the yard dispatcher's office and the other on the locomotive working in the yard around the plant. Two-way communication is provided which will enable the dispatcher to issue orders and receive confirming replies.

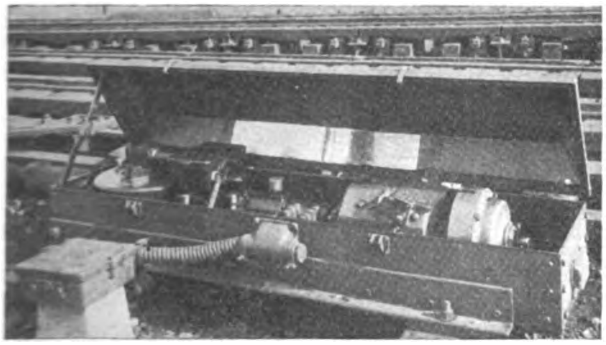

Fig. 24. Car Retarder Operating Equipment in Waterproof Enclosing Case

Electric Car Retarders

During the past two years there have been several installations of electric car retarders in hump yards of various railroads. These devices (Figs. 23 and 24) eliminate a large number of car riders and definitely speed up the classification of freight.

Installations were made by the New York Central Railroad, the Illinois Central Railroad, the New York, New Haven and Hartford Railroad, the Boston and Maine Railroad, the Texas and Pacific Railroad, the Chicago and Northwestern Railway, and the Lehigh Valley Railroad.

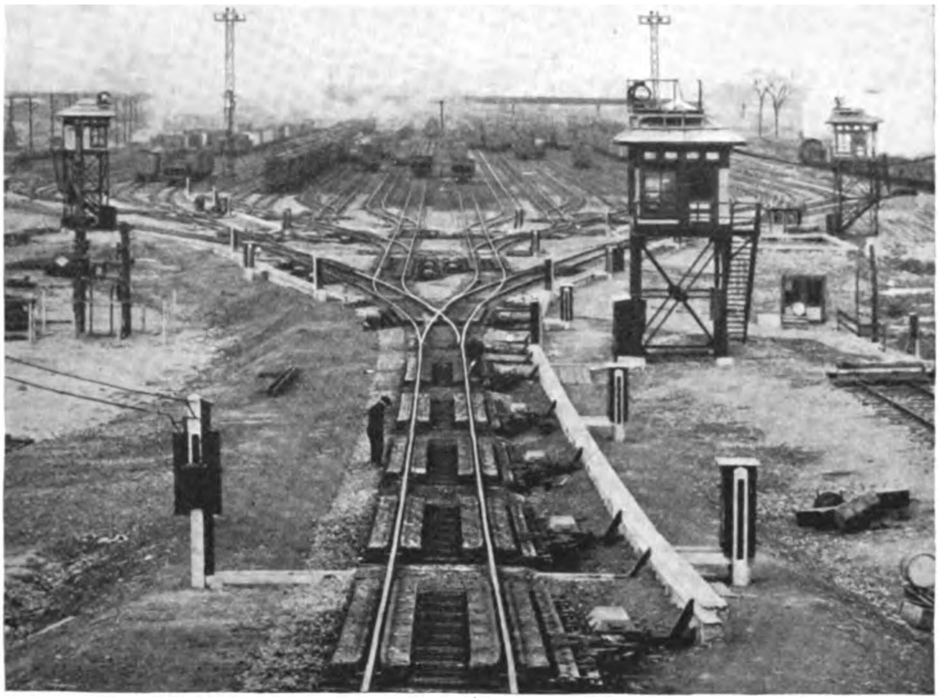

Fig. 23. Electric Car Retarders in the Selkirk Yard of the New York Central

The several hundred units now installed have afforded sufficient experience to indicate important operating economies. The electrical apparatus required for car-retarder work includes motors for the track brakes, and control and other switching equipment. The motor and brake supplied for the operation of these track brakes are coupled to a gear mechanism adjacent to the retarder, and groups of units are remotely controlled from conveniently located towers at suitable points in the yard.

WATERWHEEL GENERATORS

Construction was completed on four 40,000-kv-a. 13,800-volt 81.8-r.p.m. 3-phase 60-cycle vertical-shaft waterwheel generators for the Conowingo Development of the Susquehanna Power Company, and these machines (Fig. 25) are now in service. With an overall diameter of approximately 38 ft., they exceed in physical dimensions any waterwheel generators previously constructed.

The eight 12,550-kv-a. 14,000-volt 100-r.p.m. 3-phase 60-cycle generators for the Ohio Falls Hydro

Station of the Louisville (Ky.) Gas and Electric Company were also completed and installed. They were provided with a closed system of ventilation and surface air coolers, thereby giving effective control of the temperature and keeping the air passages permanently free from dirt.

Both the Conowingo and Louisville generators utilized steel-plate construction and were equipped with the spring-thrust type of bearing.

There was under construction during the year for the Southern California Edison Company a vertical-shaft machine rated 35,000 kv-a., 11,000/13,200 volts, 375/450 r.p.m., which was designed to deliver current at either 50 or 60 cycles depending upon the speed of operation.

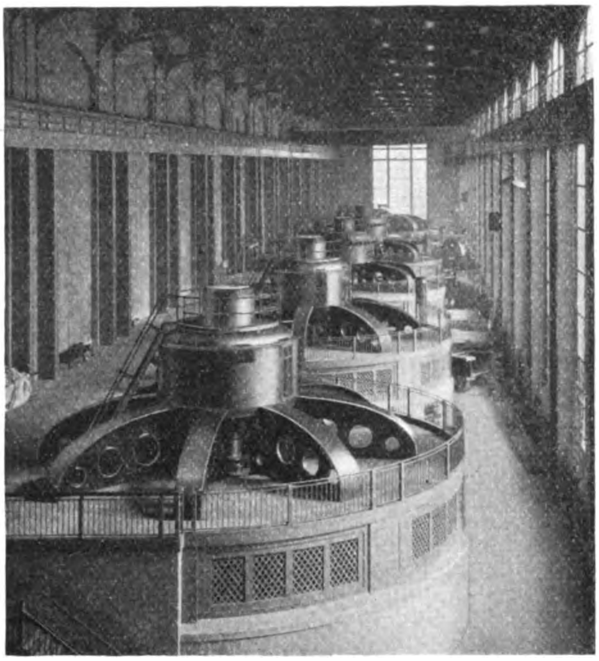

Fig. 25. Conowingo Hydroelectric Station, Showing in Foreground Two of the Four G-E 40,000-kv-a. Waterwheel-driven Generators

The most noteworthy unit for foreign shipment consisted of a 33,000-kv-a. 6600-volt 125-r.p.m. 50-cycle vertical-shaft unit for the Brazilian Hydroelectric Company. This is the third unit of this rating so far constructed for Brazil, and represents the maximum unit capacity of American machines built for foreign service.

An interesting addition to the normal testing equipment consisted of a double-cylindrical reinforced-concrete test pit (Fig. 26) installed 30 ft. below the floor of the test building, which, in turn, is located in a field a quarter of a mile from the nearest manufacturing building. The inside diameter of the pit is 45 ft. and the outside about 75 ft.; the two reinforced-concrete walls, each of which is 4 ft. thick, are separated by a 7-ft. cushion of sand. With this arrangement, even the largest rotating elements may be given over-speed tests with absolute safety to the operators, as the pit is provided with a heavy cover and the control of the tests is located in an observation building 300 ft. from the main test building, to which all circuits are brought by underground cable.

SYNCHRONOUS CONDENSERS

The first commercial application of the system of hydrogen cooling was made with a synchronous condenser installed by the New England Power Company at its Pawtucket (R. I.), substation. If the condenser were air-cooled, as are all other condensers today, its capacity would be 10,000 kv-a.; but because it is hydrogen-cooled, its capacity is increased to 12,500 kv-a. A still further increase in rating can be obtained by operating with hydrogen at higher pressures.

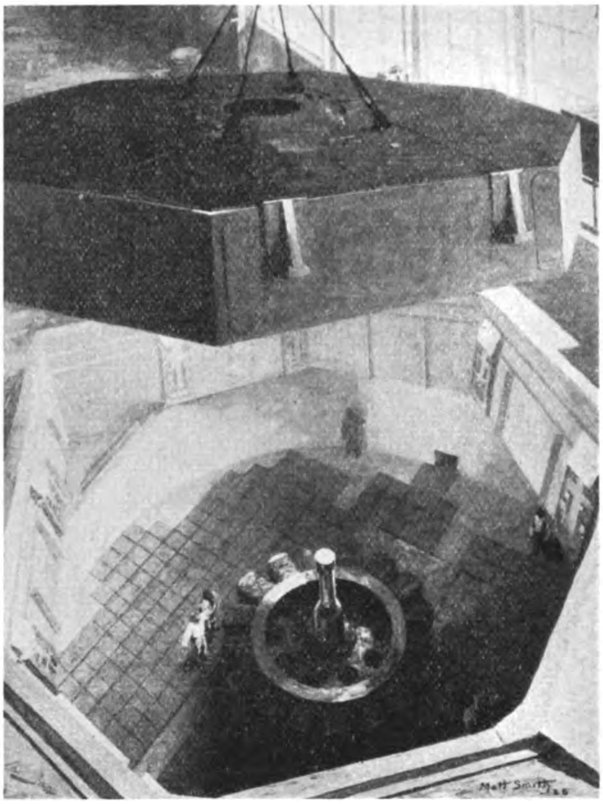

Fig. 26. Reinforced Concrete Pit 45 ft. in Diameter to Insure Safety During Overspeed Test of Large Rotating Elements

The advantages of hydrogen cooling are numerous. Not only are the losses reduced and the capacity increased for a given size of machine, but oxygen and dirt are excluded by the air-tight casing. Hydrogen also eliminates the effect of corona on the insulation.

The air-cooled machine is usually placed within a building; but the hydrogen-cooled equipment, being totally enclosed, can be located outdoors.

The synchronous condenser (Fig. 27) is enclosed in a gas-tight, explosion-proof cylinder, consisting of three main sections bolted together and provided with end bells. An extension on one end of the casing encloses the slip-ring mechanism. A carbon seal is placed around the shaft where it enters this housing, so that the brushes may be adjusted or replaced without losing hydrogen from the main shell. The bearings are supported by a structural-steel framework welded to the inside of the casing.

Full automatic operation is used to maintain the hydrogen pressure above atmosphere. A pressure-regulating switch and valve maintain the hydrogen pressure above atmospheric pressure so that leakage, if any, will be outward, thus preventing the contamination of the gas by air. A recorder in a cabinet attached to the casing gives a continuous indication of the purity of the gas, and operates an alarm if it falls below 91 per cent.

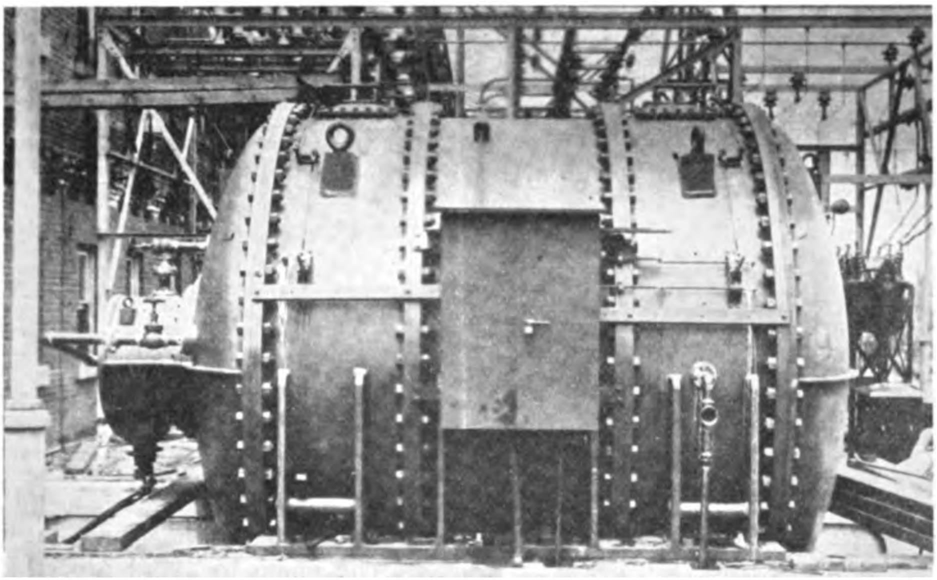

Fig. 27. Outdoor Installation of a Hydrogen-cooled Totally-enclosed Synchronous Condenser

A similar machine, but rated 20,000 kv-a. in hydrogen, has been built for the Appalachian Electric Power Company at Turner (W. Va.).

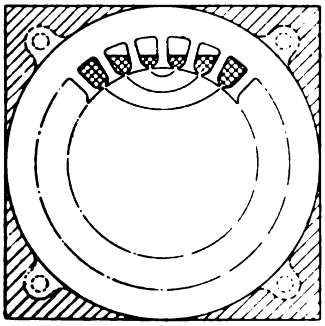

Fig. 28. Circular Type of Stator Punching with Slots of Uniform Depth, Showing Wasted Corner Material and Incomplete Use of Material at the Pole Centers

The installation of high-speed excitation systems on three 30,000-kv-a. 13,800-volt synchronous condensers at the Plymouth Meeting Substation of the Philadelphia Electric Company is of unusual interest because of the combination of extremely fast change of output with wide range of output over which the normal regulators are required to function. There are two distinct types of control now in service. The first gives an exciter build-up speed of about 6500 volts per second. The second gives 7500 volts per second and has been adjusted to control the condensers from 10,000 kv-a. lagging to 50,000 kv-a. leading, which corresponds to an exciter range of 20 to 400 volts. The exciter is rated at 250 volts but does not saturate until about 900 volts.

MOTORS

An improved single-phase repulsion-induction motor, in sizes ranging from ¾ to 2 hp. at 1800 r.p.m., is of the constant-speed high-starting-torque type for general application.

One of the most important improvements is the more efficient use of the stator punchings (Figs. 28 and 29) which was accomplished by taking full advantage of the design possibilities of the polar winding of a repulsion motor. The most desirable distribution of stator coils in a repulsion motor is a sinusoidal distribution. This means, therefore, that the number of turns in the various coils of any one pole varies according to the angle from the pole center. Full advantage has been taken of this possibility by designing a four-pole motor using a square punching

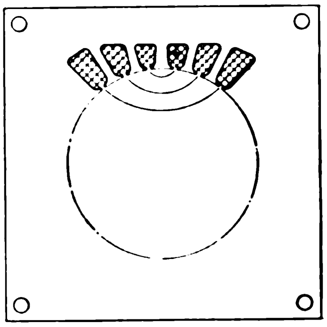

Fig. 29. Square Stator Punching with Graded Slots Resulting in Better Magnetic Utilization of the Steel

with graded slot depths, the slots being so arranged that the deep slots are placed at the corners where the maximum core is available and the shallow slots placed in the flat portion of the punching where the minimum core is adequate.

As a result of this modification the active core section is unusually large, permitting a design of low flux density and larger bore. As a motor's output is a function of the square of the rotor diameter and the length, it is therefore possible to design a motor (Fig. 30) with small overall length. Combined with this change in design, a modification was made in the commutator and brush-rigging design so that the commutator end shield has the same dimensions as the pulley end shield.

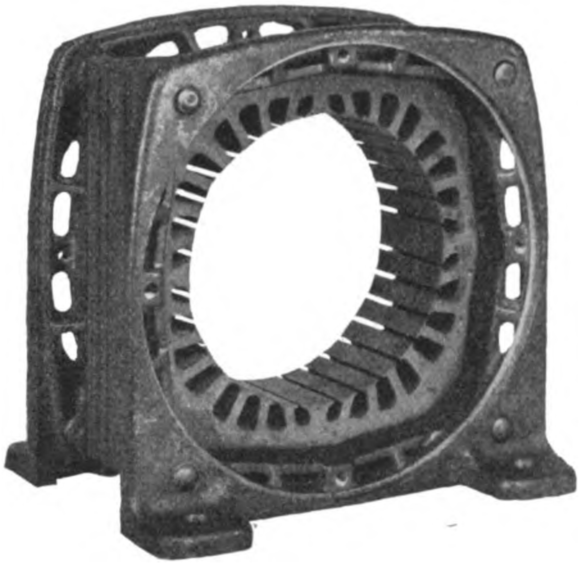

Fig. 30. Stator Core of Improved Single-phase Repulsion-induction Motor Assembled Ready for Windings

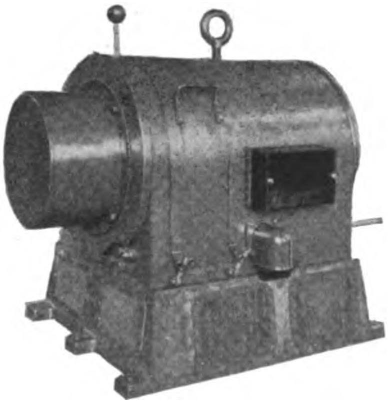

Fig. 31. Brush-shifting Shunt-characteristic Polyphase Motor Designed for Variable-speed Spinning-frame Drive

The motor is enclosed except for ventilating openings in the lower portion of each end shield. Air is drawn through the ventilating openings at the pulley end by means of an internal fan, passes around the stator laminations and out through the ventilating openings in the commutator end. This construction makes the motor practically enclosed, but in spite of the enclosure and the small size of the motor it is designed to operate within a temperature rise of 40 deg. C. This performance materially broadens the field of application, permitting the use of a standard 40-deg. motor in many cases where a larger enclosed motor would otherwise be chosen.

Rapid development in the art of designing capacitors has made this product so reliable that there has again arisen a demand for single-phase motors utilizing essentially squirrel-cage induction rotors wound like those of two-phase machines but with a capacitor across one phase to afford proper starting torque. Such motors were produced in sizes from 1/6 to 15 hp.

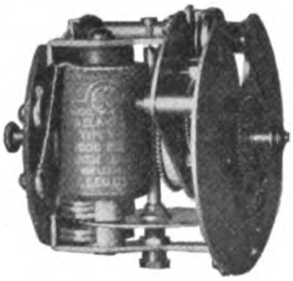

Fig. 32. Side View of Electric Clock Movement, Showing Escapement and Application of the 4-oz. Motor

Some two-speed synchronous motors rated 50/25 hp. 257/128 r.p.m. were constructed for driving ammonia compressors. They are the first motors of this type to be used for this service.

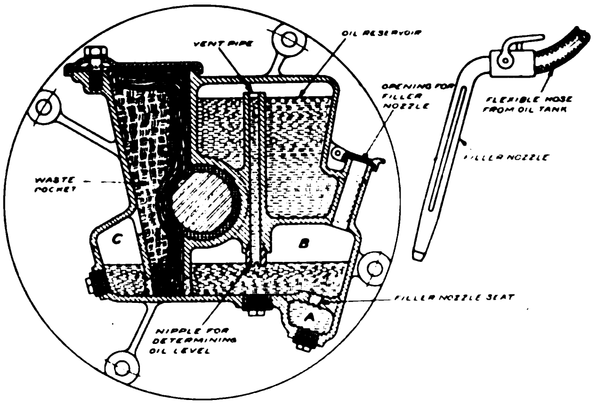
VENT PIPE
OIL RESERVOIR
OPENING FOR FILLER NOZZLE
FLEXIBLE HOSE FROM OIL TANK
FILLER NOZZLE
WASTE POCKET
C
B
A
FILLER NOZZLE SEAT
NIPPLE FOR DETERMINING OIL LEVEL

Fig. 33. Diagram of Constant-oil-level Bearing for Railway-type Motors

During the year the line of synchronous motors having induction-motor characteristics, making them suitable for general purpose application, was extended to sizes as large as 500 hp. at speeds of 1200 to 600 r.p.m. These motors utilize a skeleton-frame construction and are equipped with a compact direct-connected exciter.

Recent tests in the textile industry have indicated the desirability of applying the alternating-current brush-shifting shunt-characteristic polyphase motor for obtaining variable speed in the spinning of cotton as well as worsted yarns. The use of this motor (Fig. 31) which permits selecting the best speed over a 3:1 range, has resulted in improvement in the quality of the yarn and increased production.

A new electric clock contains a movement utilizing a very small motor of the disk type as the driving source. This motor constantly winds a small spring which in turn operates the escapement, and the application is unique in that the torque applied to the spring is automatically kept at the normal value regardless of changes in voltage or frequency. This assists in securing improved time-keeping qualities. The motor (Fig. 32) runs at an average speed of 82 r.p.m., has an input of only 1.8 watts, and weighs approximately 4 oz.

A detail improvement in railway-type motors consists of a constant-oil-level bearing (Fig. 33) designed to provide a constant oil level in the waste chamber. To add oil to the bearing, the filler nozzle is seated on the opening above *A* which is connected to the oil reservoir by an unrestricted channel.

As oil is forced into the reservoir, air escapes to the atmosphere by way of the vent pipe, chamber *B*, and around the filler nozzle. When the level in the reservoir rises to the top of the vent pipe, oil passes into chamber *B* until it overflows through the opening for the filler nozzle. This indicates that sufficient oil has been added. After the filling operation, the oil level in chamber *B* is higher than in the expansion chamber *C* and these levels are equalized by the slow passage through the waste at the bottom of the waste pocket. As oil is used, the level in chamber *B* falls below the nipple at the bottom of the vent pipe, admitting air to the reservoir and releasing oil which flows through *A* to *B*, raising the level to the proper point.

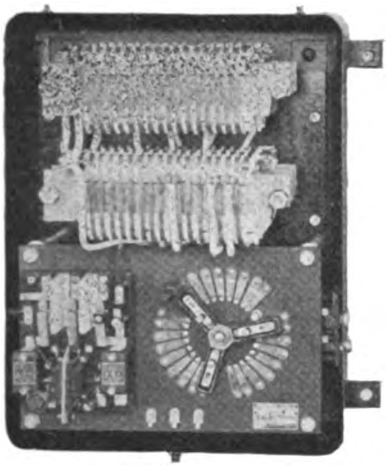

Fig. 34. Preset Speed Controller for Slip-ring Induction Motor Driving Fan

MOTOR CONTROL

A speed controller (Fig. 34) for slip-ring induction motors, and primarily intended for the control of motors driving ventilating fans in buildings, was constructed with the primary magnetic switch, dial-type controller, and speed-regulating resistance mounted in a sheet-steel enclosing case. The desired preset speed is obtained by an external operating lever; in case of overload, the overload relays can be reset by a button projecting through the front cover; and the starting and stopping of the motor can be accomplished either by the push-buttons protruding through the right side of the box, or by separate stations located at any point.

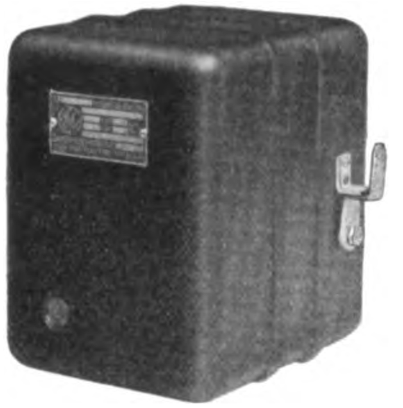

Fig. 35. Combination Three-element Controller Enclosed in Case Ready for Mounting

The ordinary installation of a motor controller involves the use of a disconnecting means for making the controller safe during adjustment, and the use of fuses to provide short-circuit protection. A small, compact device was designed which takes the place of these three elements; *viz.*, controller, disconnecting means, and enclosed fuses. This combination (Fig. 35) utilizes a magnetic switch (Fig. 36) at the front of the case and on the back of the switch base the line fuses are mounted. The unit of switch and fuses, when in place in the case, makes contact with points on the disconnecting switch in the back of the case and cannot be removed unless the disconnecting contacts are open.

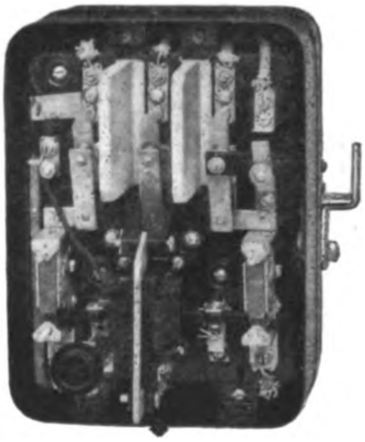

Fig. 36. Magnetic Switch with Cover Removed

This combination device provides complete overload and undervoltage protection as well as short-circuit protection, and is suitable for controlling squirrel-cage motors as large as 7½ hp. at 440 or 550 volts. The three sections are electrically connected by silver butt contacts.

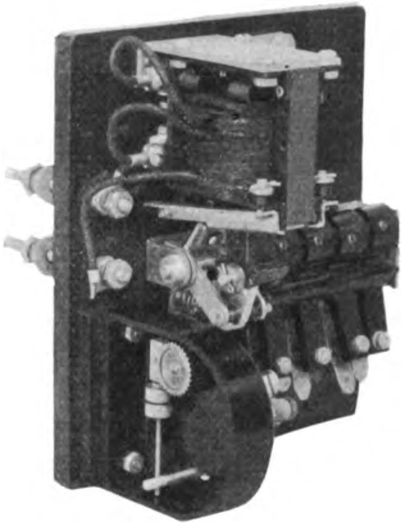

Fig. 37. Multi-fingered Definite-time Accelerating Relay

The use of the ratchet timing mechanism for securing definite-time acceleration was developed from the original single-contact device into a multi-finger form (Fig. 37) which permits the use of a single relay for actuating in succession a number of contactors.

Cam-operated switches have been used for a number of years in place of the conventional construction utilizing segments and fingers. This construction permits snap action on either opening or closing of the contacts or both. New forms of these devices were provided with double-break silver contacts, thereby eliminating shunts and giving greater arc-rupturing ability. This use of silver, when conservatively rated, prevents corrosion of the contacts which would result in over-heating.

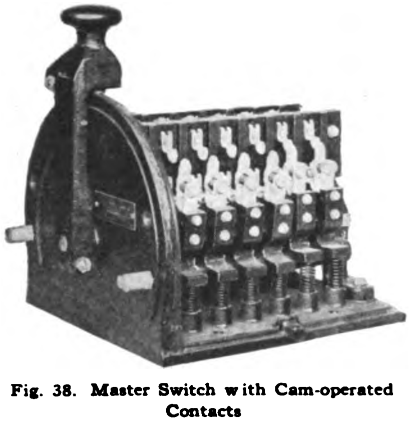

Fig. 38. Master Switch with Cam-operated Contacts

A complete line of master switches was produced (Fig. 38) requiring only a few different fundamental cams with which a great variety of combinations of contact sequence can be obtained. Since the two halves of any one can operate two independent contact mechanisms, a master switch providing a relatively large number of points can be made with a short shaft length.

A new geared-type limit switch (Fig. 39) utilizes individual cams actuating the contact arms arranged for independent adjustment of their positions on the rotating disks. Each cam can be adjusted for an infinite number of positions.

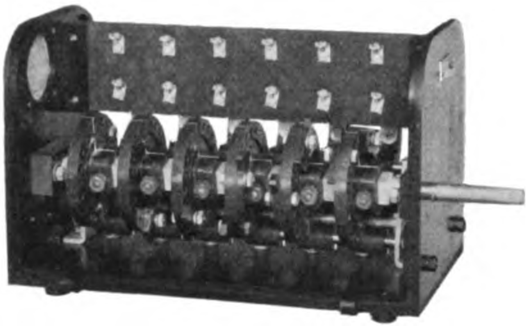

Fig. 39. Multi-contact Geared-type Limit Switch

Larger forms of cam-operated drum switches were developed (Fig. 40), a typical unit having 600-amp. contacts and providing 13 steps. It is motor operated and is utilized in the control of motor-driven central-station auxiliaries.

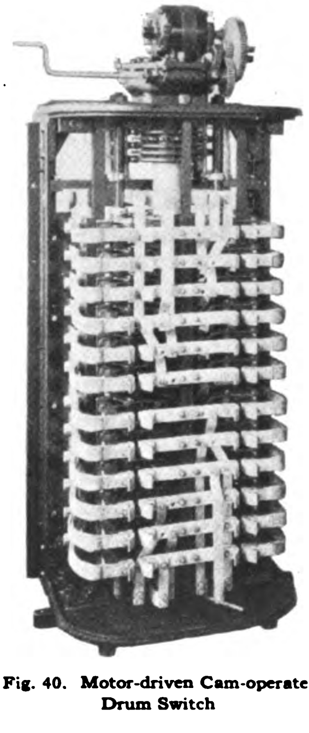

Fig. 40. Motor-driven Cam-operated Drum Switch

Control Applications

A small, compact limit switch was designed to be used principally on valve equipments, which would be capable of adjustment through a wide range of revolutions of the valve stem. By the use of intermittent gears (Fig. 41), it is possible to get an adjustment of from 1 to 1365 turns. Forward and reverse directions are independently adjustable to one tooth on the drive pinion, which corresponds to ⅙ of a revolution of the valve stem.

An interesting machine-tool equipment is that of a nine-motor planer-type milling machine with four cutters, each of which is individually driven by a direct-current motor. The heads are fed back and forth by means of an adjustable-speed direct-current motor while another adjustable-speed motor takes care of the table feed. Full push-button control is provided with such interlocking as to prevent work jamming against the cutters and automatically to lessen the feed in case of overload.

A new application was made for electrically synchronizing a warming mill and calender in the rubber industry, the speed regulator used being a modification of the regulator originally developed for paper-machine work. With this equipment (Fig. 42), the warming mill and calender are maintained at the same relative speeds over a wide range (8 to 1), thereby making it possible to use a continuous automatic feed between the mill and calender.

The increasingly severe service encountered in oil-well drilling by the rotary method and the larger motors required resulted in the redesigning of magnetic panels for this service, increasing the number of control points, using larger contactors, and also using the pendulum type of relay to give definite time-limit control on the last four or five control points, thus permitting the operator to accelerate the motor to full speed regardless of how heavy the load is but preventing him from doing so at too rapid a rate. The relay which controls the contactor giving maximum starting torque on the motor is given a longer time setting in order to give the motor time to start the heaviest load it can handle, thus eliminating the necessity for a hand-operated push-button.

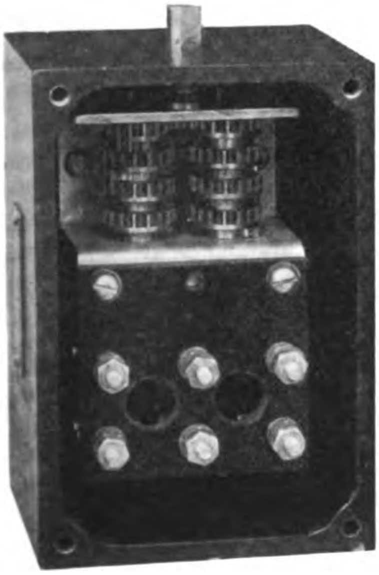

Fig. 41. Adjustable Gear-type Limit Switch for Motor-operated Valves

In addition to the accelerating contactors, the panel includes (Fig. 43) triple-pole primary reversing contactors, a master switch which may be oil immersed if desired, a temperature overload relay, and an undervoltage contactor, the latter controlled by an electrical interlock on the "off" position of the master switch.

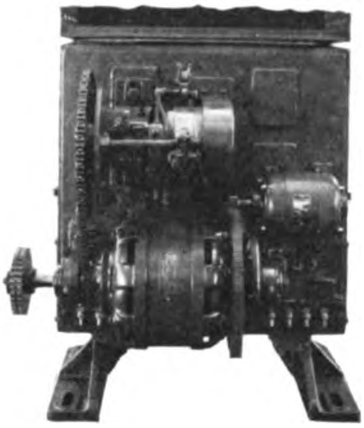

Fig. 42. Speed Regulator for Synchronous Operation of Warming Mill and Calender in the Rubber Industry

Another improvement in this control for oil-well drilling is the assembly of the panel, resistor, master switch, and entrance switch on angle-iron framework so that the complete equipment may be handled as a unit in the field.

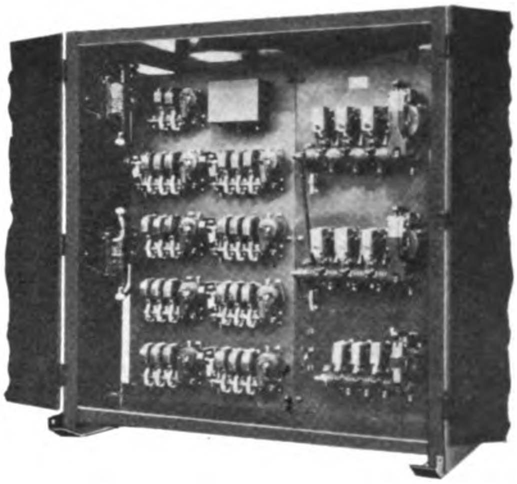

Fig. 43. Control Panel for the Rotary Drilling of Oil Wells

In addition to the 1, 3, and 5-hp. direct-current motors permissible for use in gassy mines, the line was extended to a 15-hp. size. This motor was applied to large underground conveyors for handling coal and materials, and for this purpose a reversing control unit of enclosed construction was built in accordance with the requirements of the U. S. Bureau of Mines.

The control unit (Fig. 44) includes master switches for starting and for reversing, two line contactors, and one series accelerating contactor, a starting resistor, an overload relay, and a temperature relay, the latter opening the circuit in case the starting resistor is kept in circuit too long and thus reaches a high temperature. These relays are reset mechanically by means of a rod and lever actuated by turning the operating cylinder of the master switch counterclockwise from the "off" position, therefore the relays cannot be reset in the "start" or "run" position.

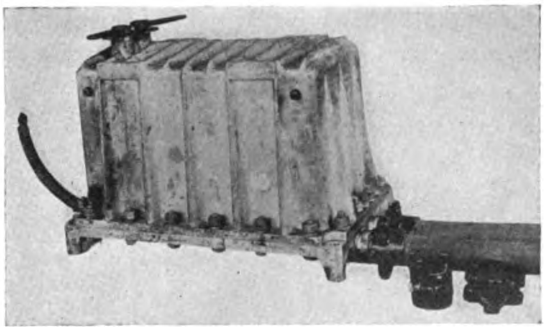

Fig. 44. Control Equipment for Direct-current "Permissible" Type Motors for Use in Gassy Mines

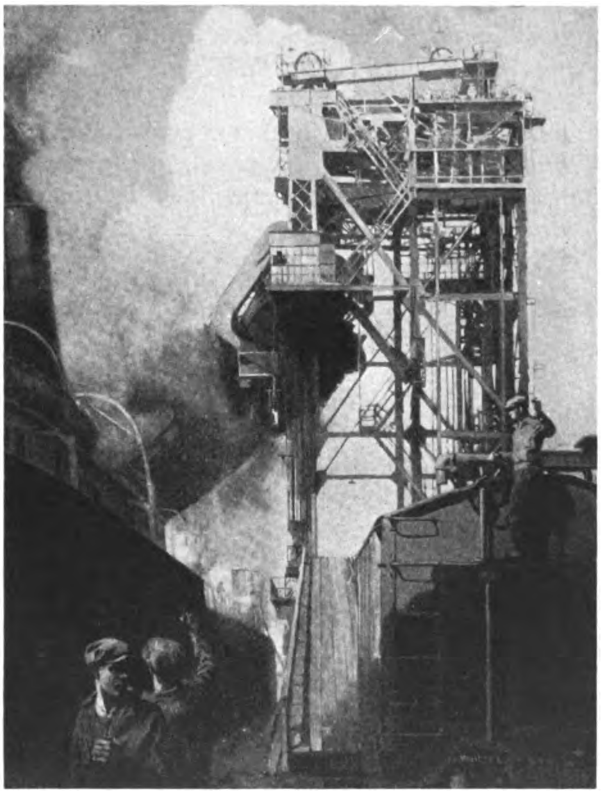

Fig. 45. High-speed Electric Car Dumper in Operation. A new dumper of this type will handle sixty cars per hour

An ingenious interlocking control system was devised for the operation, at predetermined time intervals, of chutes delivering sand, gravel, and cement to a traveling belt so as to secure automatically an accurate mixture for concrete. This arrangement eliminates the operator as a factor in securing any given mixture required.

The conveyor belt operates at a uniform speed and passes below a series of hoppers, each of which is motor-operated and provided with reversing contactors, selector switches, and definite-time relays. In the equipment already constructed, the chutes from each hopper are lowered in sequence for an interval of four seconds, after which they are raised to the closed position. The limit switches are so arranged that the operating lever is thrown in one direction by the action of the hinged chute when it is lowered and in the other direction when it is raised. When the motor is cut off the line, it also deënergizes the solenoid brake coil so that the motor will be held stationary and will not coast.

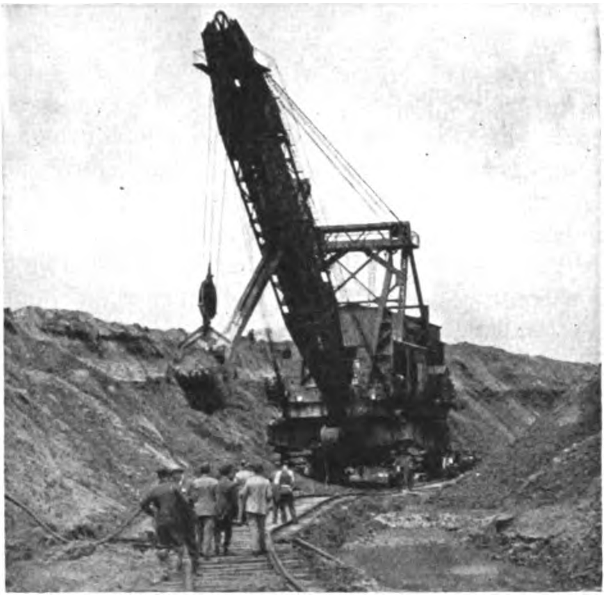

Fig. 46. 12-cu. yd. Electric Shovel in Strip Mine of Northern Illioins Coal Corp., Wilmington (Ill.)

MOTOR APPLICATIONS

Two freight-car loading cranes of an unusual type —the first to be designed for loading and unloading entire freight cars in and out of ships—are now being built for the Overseas Railway Company. They will be installed on piers at New Orleans and Havana (Cuba).

A special ship with a handling capacity of about 95 refrigerator cars will have three enclosed decks each equipped with four storage tracks and a central hatchway through which the cars will be lifted or lowered. For loading the ship, one car at a time will be run upon a special cradle on the pier. The cradle will then be picked up by the crane and lowered into the ship where the car will be run off on a storage track. At the other terminal the process will be reversed for the removal of the cars.

The hoist will be driven by two 250-hp. totally-enclosed mill-type direct-current motors having magnetic control. The trolley motor is rated 75 hp. and will also have full magnetic control.

The maximum load to be lifted is 165 tons, the hoisting speed is 50 ft. per min., and the trolley speed is 200 ft. per min. The power supply for the crane at New Orleans will be of 230 volts and at Havana of 550 volts; the motors being operated in parallel at New Orleans and in series at Havana, which admits of practically duplicate motors and control for the two cranes.

The control will be of the rheostatic type, and will be designed for operation from either the ship or the pier. Normal operation will be from the pier on which the crane is located, through a master switch; but by means of a cable and plugging arrangement, other master switches on board the ship can be used to control the crane. Although either point can be selected for control purposes, both cannot be used at the same time.

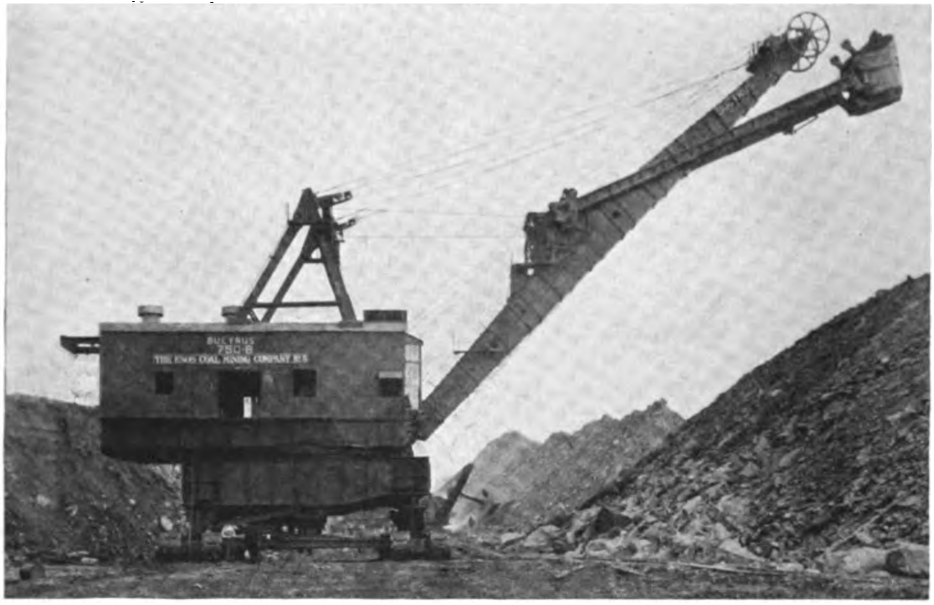

Fig. 47. 12-cu. yd. Electric Shovel in Strip Mine of the Enos Cook Company, Oakland City (Ind.)

An electric car dumper, which is expected to set a new record for speed, is under construction for the New York Central Railroad. It will be located at Toledo, adjacent to the first all-electric car dumper (Fig. 45) installed on the Great Lakes.

The new dumper will be of the lift and turnover type with a variable dumping position; *i.e.*, the car can be raised and dumped at any height between the maximum and minimum pin positions. The mule haul will be driven by two 500-hp. shunt-wound direct-current motors, and the cradle by two motors of the same type and rating. Control will be of the variable-voltage type, incorporating special features to meet the unusual requirements of this service. Both alternating and direct-current motors will be used on the dumper, the total equipment involving an aggregate of approximately 3000 hp.

Power will be received at 6600 volts, 3 phase, 60 cycles. A portion will be transformed to 440 volts for the operation of the alternating-current motors, and the remainder will be converted—by means of two motor-generator sets—for the operation of the direct-current equipment.

An interesting feature of this equipment will be the use of electrically-operated car retarders for spotting cars on the cradle of the car dumper and also along the mule-haulage runway. With the use of such car retarders, it is expected that the performance of the car dumper will be speeded up considerably, by reason of the time saved between the end of the mule-haulage and the beginning of the cradle-hoist operation. A number of car riders will also be eliminated, making for lower operating expense and reducing the hazard to human life.

Electric Shovels

For the first time a number of electric shovels of 12-cu. yd. capacity (Figs. 46 and 47) were placed in operation, and others of this size are under construction. Prior to 1928, the largest excavating machine of this type was the 8-cu. yd. or 300-ton shovel which, on a few occasions, had been fitted with a 10-cu. yd. dipper.

The electrical equipment designed for this type of machine includes special generator-field control and special motor-generator sets. A typical motor-generator set for this service consists of five units, the synchronous driving motor being rated 800 hp., 3 phase, 60 cycles, 4000 volts, 1200 r.p.m.; the hoist, swing, and crowd generators being rated respectively 400 kw., 200 kw., and 150 kw., all differentially compound wound. The fifth unit is a 35-kw. 125-volt constant-potential exciter. The generators in these sets have characteristics which are exceptionally well suited to handling the extreme variations of current demand encountered in shovel work.

The typical hoist equipment (Fig. 48) comprises two 200-hp. separately-excited motors operating with armatures connected in series, the swing and crowd motors being rated 100 hp. and 150 hp. respectively. These motors are all of the mill type and are provided with roller bearings and inbuilt fans. They are similar in general design to the type of motor used in steel mills.

The auxiliary equipment includes a dead-front steel cabinet-type switchboard, railway-type reciprocating air compressor, and special transformers and controllers.

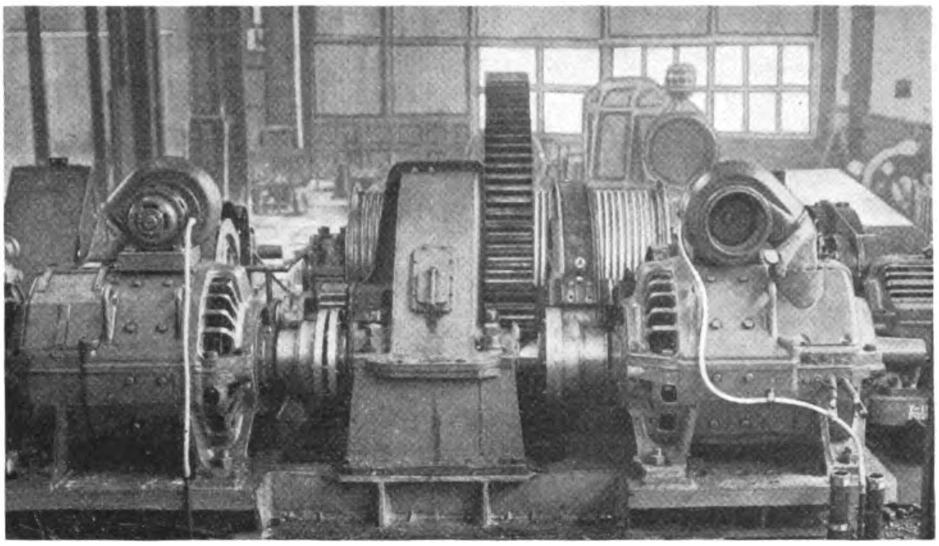
Fig. 48. Typical Hoist Equipment for Large Shovels, Showing Direct-current Hoist Motors with Induction-motor-driven Blowers

It is interesting to note that one of these shovels made a world's record for material moved by an excavating machine of this type by handling a total of 15,497 cu. yd. of overburden in 24 hr., divided into three 8-hr. shifts.

The records made by these 12-cu. yd. shovels will be far surpassed by the result which will be obtained from a 15-cu. yd. electric shovel which is now nearing completion and will be the largest in the world. While this new machine is only 20 per cent larger in dipper capacity, the actual increase in power required is about 100 per cent as compared with existing maximum-sized shovels.

Some idea of what this new shovel will be capable of accomplishing can be understood from the following performance estimates: A single dipper load of earth will be sufficient to fill a trench 1 ft. deep, 6 ft. wide, and 68 ft. long, or it would fill eight large motor trucks. Its scope of operation will be unusual as the boom will be 120 ft. long and the dipper stick over 80 ft. in length, so that it will be able to lift material to a maximum height of about 100 ft., and reach over a radius of 100 ft. from the center of operations.

All the shovel operations will be controlled by one man by means of two hand levers and one set of foot pedals. The control will be of the variable-voltage type, by means of which the generator voltage is changed by varying the generator field. This allows rapid maneuvering, quick reversing, and also limits the torque to a definite and safe value so that the mechanical parts will not be subjected to undue strains or stresses. The total weight of the shovel will be approximately 1350 tons, the previous record weight being 550 tons.

Power will come to the shovel through a trailing cable approximately three inches in diameter, wound on a cable reel attached to the rear of the shovel and of sufficient length to allow the shovel to operate at a maximum distance of 1000 feet from the point of power supply. The electric supply to the shovel will be in the form of alternating current at 4000 volts.

The hoisting motion of the shovel will be actuated by two 450-hp. variable-voltage motors operating at speeds up to a maximum of 500 r.p.m., while two pairs of 150-hp. variable-voltage motors of the same type will be used for the swing and crowd motions.

The motor-generator and exciter will have a combined weight of approximately 65 tons and this equipment will all be assembled on a single self-supporting base which will be given a three-point suspension mounting.

Mining

The Sullivan Mining Company, Kellogg (Id.), installed the first commercial-size plant in this country to utilize the Tainton process for the electrolytic reduction of zinc. This process involves the use of strong acid and high-current density for electrolysis. Current for the tank circuits is supplied by two 3-unit 4000-kw. motor-generator sets.

The Anaconda Copper Mining Company, Anaconda (Mont.), put in operation an electrolytic zinc plant requiring larger motor-generator sets than had heretofore been used for this process. There are four of these record-size three-unit sets (Fig. 49), each rated 5500 kw.

The Cerro de Pasco Copper Corporation, Peru (S. A.), adopted twenty-five equipments for the Cottrell process of electric precipitation, each equipment consisting of a 15-kv-a., 50,000-volt transformer with induction regulator and control for the transformer and motor-driven mechanical rectifiers.

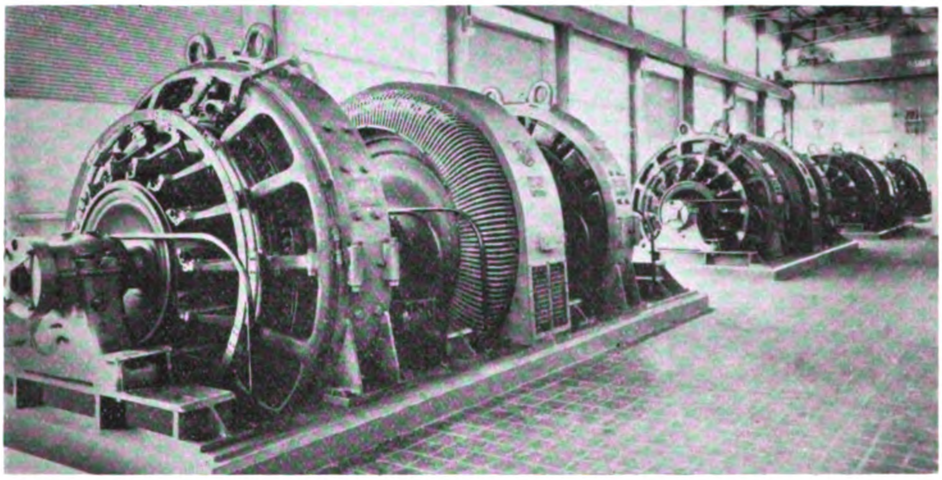
Fig. 49. Four 5500-kw. Motor-generator Sets for Electrolytic Service

This control equipment is of the magnetic type with the main circuits operated by push buttons. This is the first time this type of control has been used for this service and the apparatus will be operated at an altitude of 12,200 ft.

The Peabody Coal Co. of Chicago installed, at its Mine No. 53, Springfield (Ill.), a hoist which while not of extraordinary size, is yet worthy of note because of the high rope speed and the number of trips made per hour. It is operated by the variable-voltage system of control and consists of an 850-hp. 116-r.p.m. direct-current motor direct connected to the hoist drum and a 750-kw. synchronous motor-generator set for supplying the direct current.

The equipment was designed for balanced operation and to make 230 trips per hour from a depth of 282 ft.; and in order to do this the rope speed reaches 3300 ft. per minute. The hoisting cycle is made up as follows: acceleration 5 sec., full-speed running 1.65 sec., retardation 5 sec., caging 4 sec.—total, 15.65 sec.

The control is of the magnetic type with a master switch for handling the contactors. Time-limit relays are provided to limit the closing and opening of the contactors to values which will prevent excessive current being taken by the hoist motor.

The Tennessee Coal, Iron & Railroad Co. of Birmingham (Ala.), adopted an 1800-hp. 260-r.p.m. 3-phase 60-cycle induction-type hoist motor, a duplicate of two equipments already installed, except that the new motor will be equipped with magnetic control whereas the previously installed units used liquid rheostats. This is the largest induction mine-hoist motor with magnetic control installed in this country. The control provides dynamic braking to allow for lowering loads at reduced speeds without excessive wear of the mechanical brakes.

During the year, the first fabricated steel-frame induction motors (Fig. 50) for mine hoisting service were installed.

The H. C. Frick Coke Co. put into operation a conveying equipment approximately 2½ miles long for transporting coal from the mine to a dock. It consists of twelve sections varying in length from 340 to 2217 ft. and was designed to deliver 1800 tons of coal per hour. The electrical equipment includes three 300-hp., three 200-hp., four 175-hp., one 125-hp., and one 75-hp. 3-phase 60-cycle wound-rotor induction motors.

Steel Mills

The existing capacity of G-E motors driving rolling mills (Fig. 51) was increased during the year by the addition of alternating-current and direct-current motors, 300-hp. and above, totaling close to 100,000 hp. Of this total, approximately 82 per cent are direct-current machines. This proportion is due largely to the installation of several new continuous mills with individual motor drive for each stand of rolls.

Unusual features characterize the 36-in. reversing Universal slabbing mill of the Wheeling Steel Corporation at Steubenville (O.), which is the first slabbing mill to be installed in this country with horizontal and vertical rolls driven by separate reversing motors. The horizontal roll motor is a single-unit 7000-hp. 50/100-r.p.m. 750-volt direct-current machine, and the vertical roll motor is a 1650-hp.

112.5/270-r.p.m. 750-volt direct-current machine. Power for these two motors is supplied from a flywheel motor-generator consisting of one 5000-hp. 400-r.p.m. induction motor driving three 2400-kw. d-c. generators with one 50-ton flywheel.

At this same plant there is a wide-strip-mill installation consisting of alternating-current and direct-current motors aggregating more than 20,000 hp.

Another interesting installation using special means for obtaining constant-speed ratio between various driving motors will be made at the Sharon (Pa.) Plant of the Sharon Steel Hoop Company. Seven 600-volt d-c. motors totaling 12,000 hp. will be used to drive a continuous-strip mill. Two synchronous motor-generators, each consisting of a 5600-kv-a. 514-r.p.m. synchronous motor and two 2300-kw. 600-volt d-c. generators, will supply power to the mill motors.

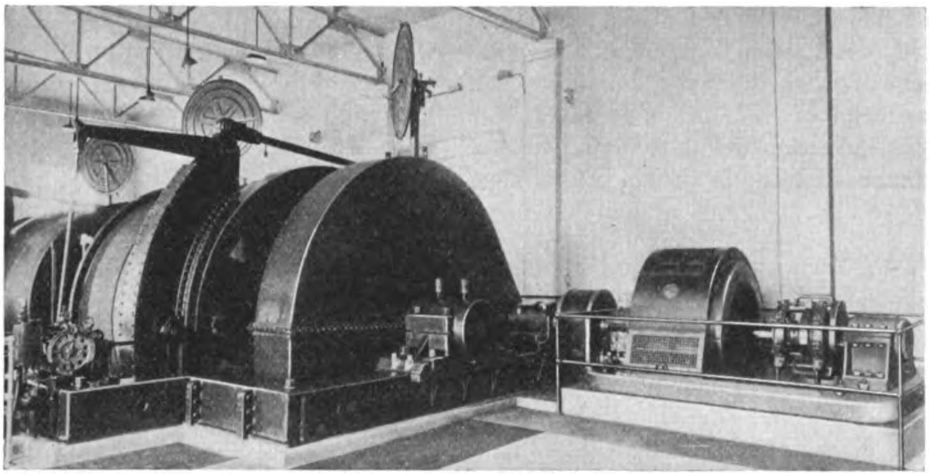

Fig. 50. Pioneer Installation of Fabricated Steel-frame Induction Motor for Mine-hoist Service

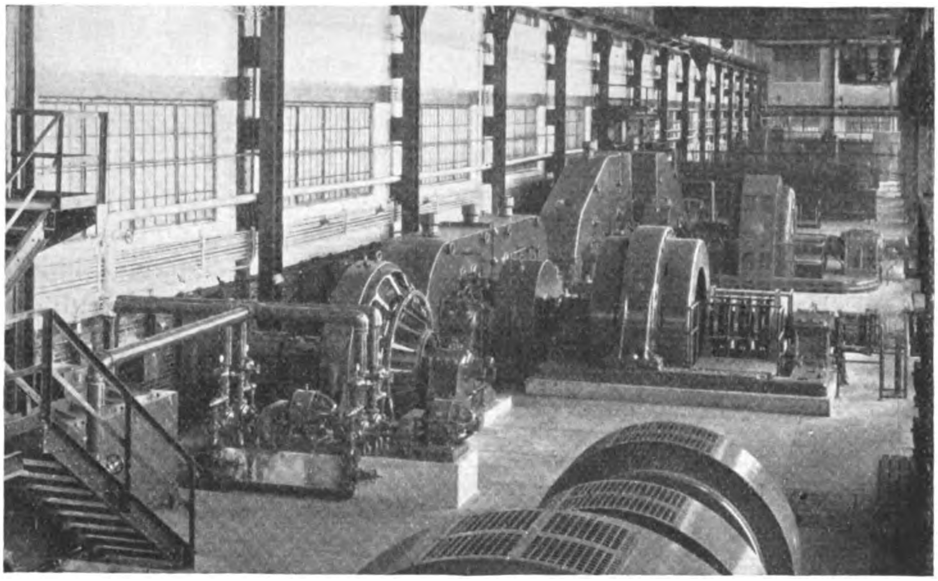

Fig. 51. Motor Room of a Continuous Skelp and Sheet-bar Mill in which Are Installed Drives of Three Distinct Types: D-c., Induction, and Synchronous Motors

The electrification of a double-stand continuous-rod mill at the plant of the John A. Roebling's Sons Company, Trenton (N. J.), will require four direct-current motors: one 2500 hp., one 600 hp., and two 800 hp. Power for these motors will be supplied by a synchronous motor-generator consisting of a 4500-kv-a. 720-r.p.m. synchronous motor direct connected to two 1750-kw. d-c. generators. A special control is provided for each of the direct-current motors whereby the speed ratio between motors can be automatically maintained within a fraction of a per cent.

Direct-current reversing motors to replace steam-engine drives were adopted by the Illinois Steel Company for its South Chicago Plant. A 7000-hp. 50/120-r.p.m. 750-volt double-unit reversing motor will be used to drive a 40-in. blooming mill. Power for this reversing motor will be supplied from a flywheel motor-generator consisting of a 5000-hp. induction motor, a 50-ton flywheel, and two 3000-kw. generators. A 3500-hp. 50/120-r.p.m. 750-volt d-c. reversing motor will drive a 32-in. structural roughing mill, and a 6000-hp. 75/140-r.p.m. 750-volt d-c. motor will drive the 28-in. structural finishing mill. A flywheel motor-generator consisting of a 7500-hp. induction motor, a 50-ton flywheel, and three 3000-kw. generators, will furnish power to the 3500-hp. and 6000-hp. structural mill motors.

Other engine drives to be replaced are at the plant of the Youngstown Sheet and Tube Company, Youngstown (O.), where a 5000-hp. induction motor will be utilized to drive an 18-in. continuous billet mill. A 2000-hp. 275/550-r.p.m. 600-volt d-c. machine will replace an engine on the finishing stand of a 10-in. skelp mill.

The electrification of the finishing stands of the 13-in. skelp mill at the McKeesport Plant of the National Tube Company will involve the installation of six direct-current motors totaling 6600 hp.

Changes in the layout of the rail mill at the Lackawanna Plant of the Bethlehem Steel Company were completed during the year. The 7000-hp. d-c. motor (Fig. 52) driving the 44-in. reversing blooming mill and the 5000-hp. d-c. motor driving the 36-in. reversing roughing mill are now in operation. An interesting feature of the control for the auxiliary motors in the Lackawanna rail mill is the use of only one control wire between each master switch in the operator's pulpit and its contactor panel in the control room. This ingenious system retains all the required features of forward and reverse control, undervoltage release, and ability to transfer to a spare contactor panel by simply throwing a single-pole double-throw switch.

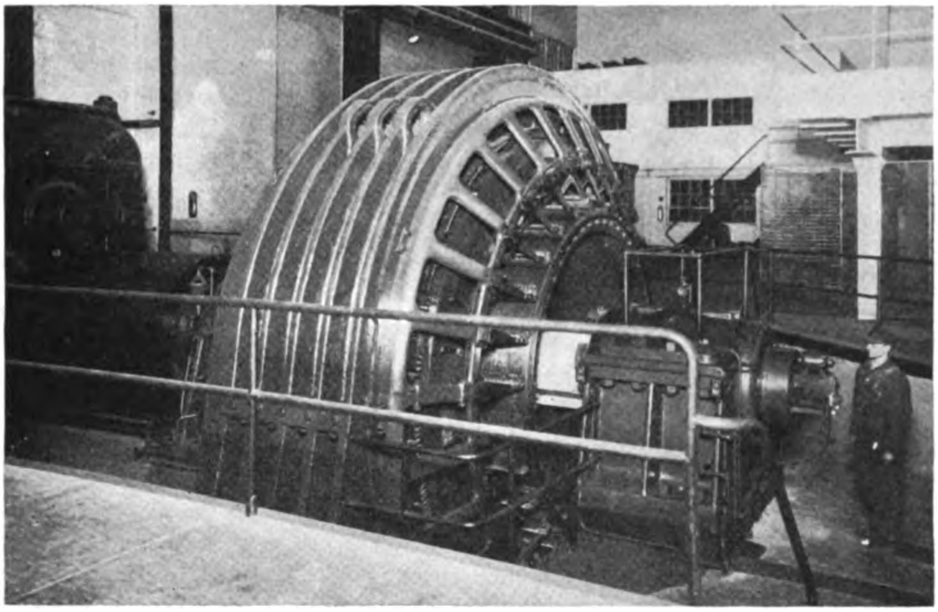

Fig. 52. 7000-hp. Reversing Motor Driving 44-in. Blooming Mill, Bethlehem Steel Co., Lackawanna (N. Y.)

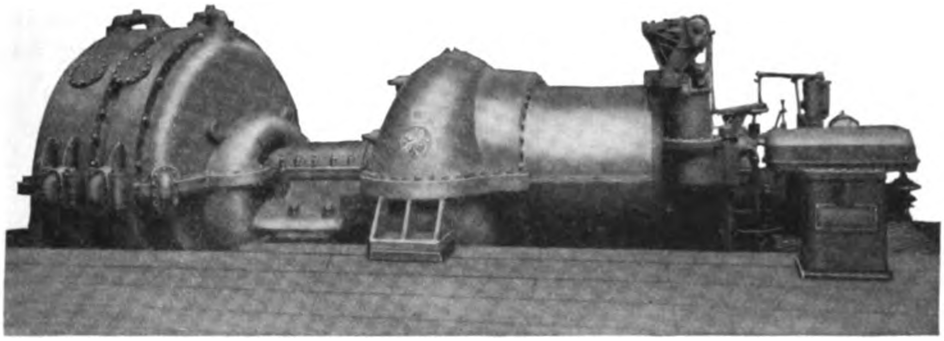

Fig. 53. Typical Turbine-driven Compressor Applying Modern Central-station Practice to Blast-furnace Blowing

CENTRIFUGAL COMPRESSORS

The Youngstown Sheet and Tube Company completed the installation at Youngstown (O.), of three 60,000-cu. ft. blast-furnace compressor units each driven by a 6850-hp. 14-stage condensing turbine. This installation incorporates the very latest practice in power-plant design and construction. Steam is generated at 400 lb. 700 deg. F. and the condenser equipment reduces the back pressure to 2 in. Hg. abs. Each turbine is arranged for steam extraction from three stages for heating boiler feed water.

The Youngstown installation (Fig. 53) is the first to apply modern central-station practice to blast-furnace blowing equipment.

The capacities of single-stage compressors were greatly extended by the use of higher speeds made possible by new alloy steels and accompanied by designs of steam turbines and speed increasing gears made to take advantage of the characteristics of these materials. For example, turbine-driven coke-oven exhausters (which are required to deliver gas of 0.38 specific gravity with inlet suction of 10 in. H_2O and temperature of 100 deg. F. at 4.0 lb. pressure) had previously been built with two or more stages in series, but with the new compressors these conditions can be met with a single stage.

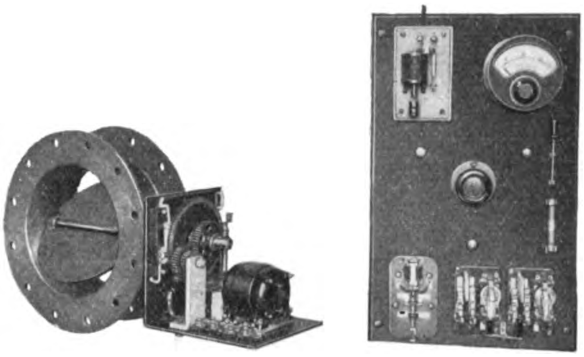

Fig. 54. Motor-operated Gate and Control Mechanism for Constant-weight Cupola Blowers

An ingenious motor-operated gate and control mechanism (Fig. 54) which was developed for cupola blowers insures the delivery of a constant weight of air to the cupola regardless of variations in temperature and barometric pressure.

This control operates an artificial restriction placed in the pipe between the blower and the cupola, which compensates for changes in cupola restriction as well as for changes in atmospheric conditions. The design is based on the fact that a certain weight of oxygen is required to burn a certain weight of carbon, and that the only way to insure the delivery of a constant weight of oxygen is to vary the volume of air to meet changing conditions of operation. The new mechanism, when once adjusted, performs this function automatically.

PAPER MILLS

A unique electrical equipment was adopted for a sectional paper-machine drive at the Brown Paper Mills Company, at Monroe (La.). The paper machine is a 178-in. machine of a standard type for the manufacture of kraft paper of varying weight from 20 lb. at 1000 ft. per min. to 250 and 300 lb. at 100 ft. per min. Such heavy-weight paper has never before been made on a Fourdrinier machine.

The range in speed from 100 to 1000 ft. per min. is the widest range ever attempted with a sectional electric drive and called for radical departures from previous methods of operation.

The electric drive consists of nine motor units driving the individual sections of the paper machine which are held in relative speed adjustment by means of synchronous dynamometer speed regulators. Each motor unit receives its power from a separate generator which forms a part of two six-unit motor-generator sets (Fig. 55), the speed regulators working on the generator fields rather than the motor fields and maintaining speed by armature-voltage control on the motors rather than by motor-field control. This feature renders greater torque available in the motors and greater stability than would otherwise be possible. The master set which controls the speed of the various sections of the paper machine also receives its power from its own individual generator, which forms one unit of the motor-generator sets, and the control of the whole machine is obtained from a single multiple-circuit rheostat (Figs. 56 and 57) which varies the voltage on all of the generators simultaneously, thus permitting the operation at any speed between 100 and 1000 ft. per min. with the utmost ease.

This equipment is the only multiple-generator control system so far installed on a paper machine. It gives full voltage control on each individual motor unit and eliminates all starting resistors, starting contactors, etc.

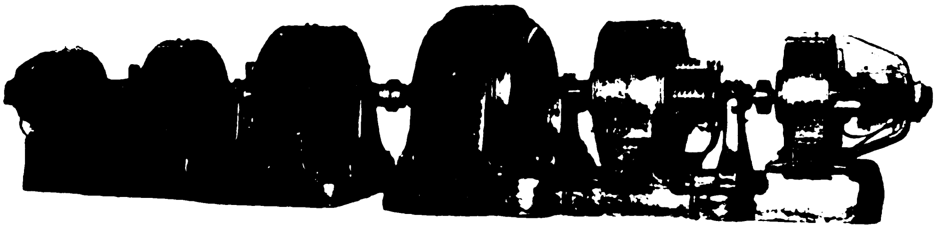

Fig. 55. Six-unit Eight-bearing Synchronous Motor-generator Set Designed for Sectional Paper-machine Drive

The Kayderos Paper Company at Rock City Falls (N. Y.) had been making crepe and tissue satisfactorily on two small paper machines and had operated them with semi-sectional drives consisting of one brush-shifting motor on the wet end and one on the dry end. These drives were satisfactory when making crepe paper because the natural stretch in this kind of paper took care of any slight variations in speed between the motors.

However, the desire to manufacture flat tissue introduced difficulties and called for some means of tying these motors together synchronously. This was done by modifying the synchronous dynamometer speed regulator so that the stator frame of the regulator motor was chain-connected to the brush mechanism of one brush-shifting motor and its rotor was driven from the same motor through a chain reduction. The stator of the regulator receives its power from a small alternator driven from the other motor. These two equipments are the first of their kind.

The sectional paper machine equipment adopted by the Warren Manufacturing Company for installation at its Warren-Glen Mill, for driving a cylinder machine, consists of four motors comprising the first wet-end section, three press sections, two dryer sections driving the dryers through two in-driving shafts, with the two sections geared together and operating as one unit, and two calender sections. The total speed range is 12:1 from 15 to 180 ft. per min., and the machine will be used for making rope and jute papers ranging from approximately 50 to 400 lb. per ream. The range of 15 ft. per min. to approximately 102 ft. per min. is obtained by armature-voltage control and the remaining range from 102 to 180 ft. per min. by shunt-field control.

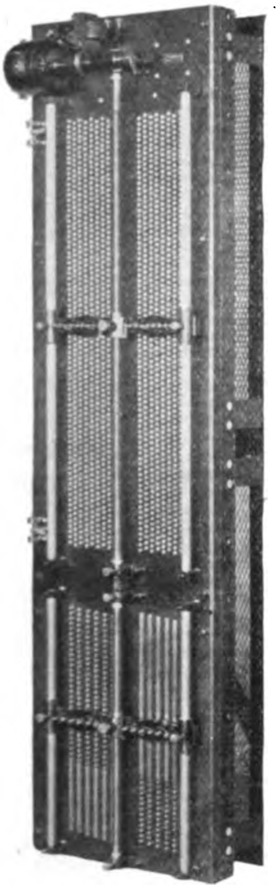

Fig. 56. Motor-operated Multi-circuit Rheostat for Sectional Paper-machine Drive

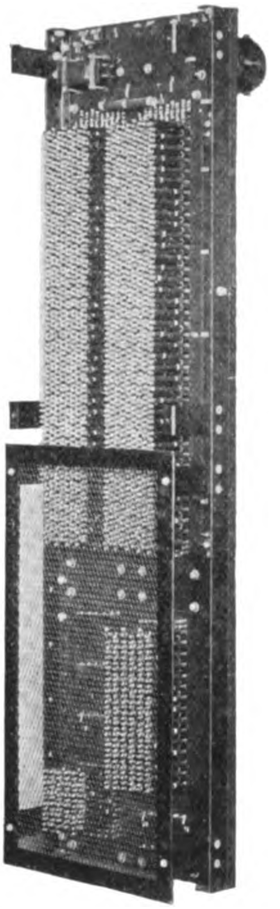

Fig. 57. Back View of Sectional-drive Paper-machine Multi-circuit Rheostat

ELECTRIC ELEVATORS

Two important improvements were introduced into high-speed elevator practice.

The automatic control of the rates of acceleration and retardation had previously been deficient in some respects and it had been impossible to achieve in practice the maximum economy in time of acceleration and retardation except by a serious sacrifice in riding qualities. The problem was solved by applying to the generator-voltage-control type of elevator drive a small auxiliary direct-current machine to act upon the generator field during acceleration and retardation. By this means the acceleration and retardation are caused to begin at very moderate rates, increase to higher rates, and again diminish as the speed change nears completion. The modulation of the acceleration and retardation in this manner makes possible the use of much higher maximum and average rates of acceleration and retardation than would otherwise be comfortable.

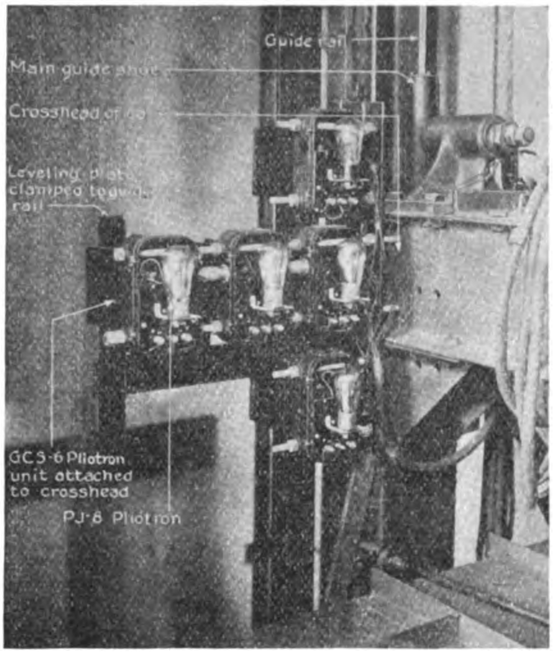
Guide rail
Main guide shoe
Crosshead of car
Leveling plate clamped to guide rail
GCS-6 Pliotron unit attached to crosshead
PJ-8 Pliotron

Fig. 58. Pliotron Units and Tubes Mounted on Top of Elevator for Use with Pre-registering Elevator Control

An automatic levelling system was developed which embodies a radical departure from previous practice. In this system the position of the car with respect to a floor operates radio-frequency devices (Fig. 58) which control the levelling speed of the elevator accordingly. The unusual merit of this arrangement is that the response is obtained by parts on the car and parts stationary in the hatchway which coöperate accurately without mechanical engagement; in fact, through a minimum clearance of about $\frac{3}{8}$ in. Thus various difficulties arising from noise, mechanical deterioration, and loss of accuracy by wear are eliminated.

A notable installation is nearing completion in which both of these improvements are incorporated. This is the Union Trust Building at Detroit (Mich.) to be occupied in 1929. Sixteen of the elevators in this building are designed for operation at 800 ft. per min., and the first of these has been regularly used for several months at this speed, for serving the building construction force.

ELECTRIC MELTING AND REFINING FURNACES

There was a notable increase in the use of arc furnaces, particularly for the production of steel castings and of non-ferrous alloys in industries where the operations are more or less intermittent in character. This interest was exhibited in foreign countries as well as in the United States. The growth in the central-station industry is making possible the economical use of the arc furnace in the smaller industries, and a large number of the smaller sizes of arc furnaces were installed during the year.

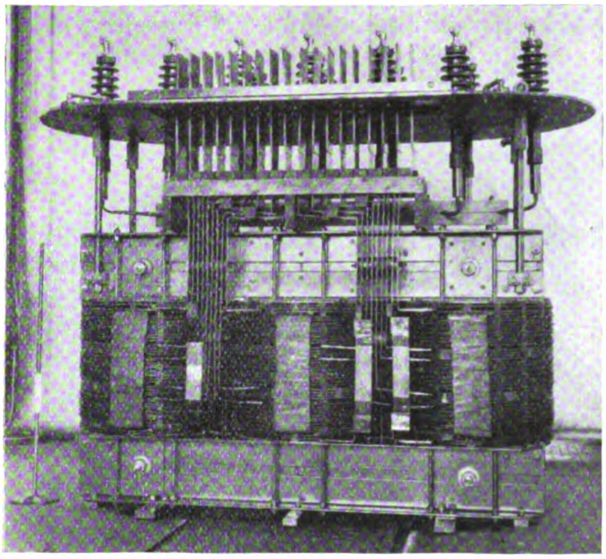

Fig. 59. Low-voltage Side of 20,000-kv-a. Three-phase Transformer for Electric-furnace Service

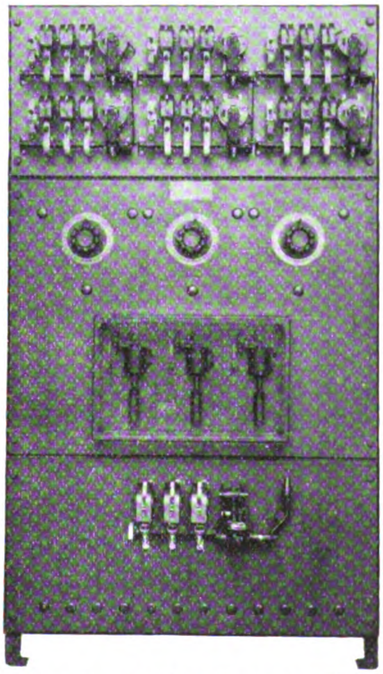

Fig. 60. Automatic Alternating-current Electrode Regulator for Carbide Furnace

In the larger industries there was a marked trend toward large furnaces, particularly for the production of alloy steels. During the year a twin-chamber arc furnace, equipped with a total of 20,000 kv-a. transformer capacity (Fig. 59), was constructed.

Heretofore, direct-current equipment has been necessary for all automatic electrode regulators of arc furnaces and this necessitated a motor-generator set to supply the direct current. To overcome this objection, a new type of automatic alternating-current regulator (Fig. 60) was designed.

The high-frequency—or coreless—induction furnace made marked progress in the production of high-grade ferrous alloys, and a number of them were installed by various metal industries.

ELECTRIC WELDING

Many new welding operations and handling mechanisms for new applications of automatic metallic arc welding were produced. Two of those which were outstanding are:

(*a*). A multiple-arc welding machine for automatically arc welding pipe up to 36 ft. in length, 7 ft. in diameter, and $\frac{5}{8}$ inch in thickness. This is the largest arc-welding pipe machine (Fig. 61) in the world.

(*b*). Welding the bottoms to the sides of inner casings of $5\frac{1}{2}$-cu. ft. refrigerators. The material is 16 gauge and the weld has to be covered with vitreous enamel without pitting.

A 400-amp. 50-deg. C. rise welding generator with a current range of 100 to 500 amp. was added to the line of single-operator sets; and the sets of 200 and 300-amp. capacity were redesigned to meet N.E.M.A. standards. A new design of reactor giving improved welding characteristics was added.

Fig. 61. Multiple-arc Welding Machine for Automatically Arc Welding Pipe up to 36 ft. in Length and 7 ft. in Diameter

The increase in the use of electric arc welding resulted in the production of a Fordson-driven 300-amp. arc welder (Fig. 62) for use where there is no other source of electric power. The Fordson not only supplies the power for the welder but carries it to and from the work.

Rapid strides were made in the fabrication of steel buildings by the electric arc-welding process and an all-arc-welded building (Fig. 63) 145 ft. wide by 550 ft. long and requiring about 1000 tons of steel was constructed. Two other all-welded buildings are now being built by the same process.

INDUSTRIAL HEATING

Electric heating equipments were built for two continuous annealing lehrs used in the manufacture of sheet glass. These lehrs are about 700 ft. long and 7 to 12 ft. wide. About half the length, or 350 ft., is heated and the temperature controlled at equally-spaced points along the lehr so that a temperature curve of the required characteristic is secured while the glass moves through the lehr in a continuous sheet. The connected load is 900 to 1600 kw.

For vitreous enameling, a number of continuous conveyor furnaces (Fig. 64) of a novel type were built in the shape of a "U" with the heating chamber at the curved end; the ingoing work passing the outgoing work in the forward extension chamber and absorbing a portion of its heat. The conveyor extends out into a room for a considerable distance which gives the coated ware opportunity to dry before entering the furnace and the finished ware an opportunity to cool to handling temperature for removal. These furnaces can be arranged in a group of three, one for the ground coat and the other two for the finish coats, the ware being taken from one conveyor and dipped and placed on the next conveyor, thus reducing the handling required and giving a large output per unit of floor space and per operator.

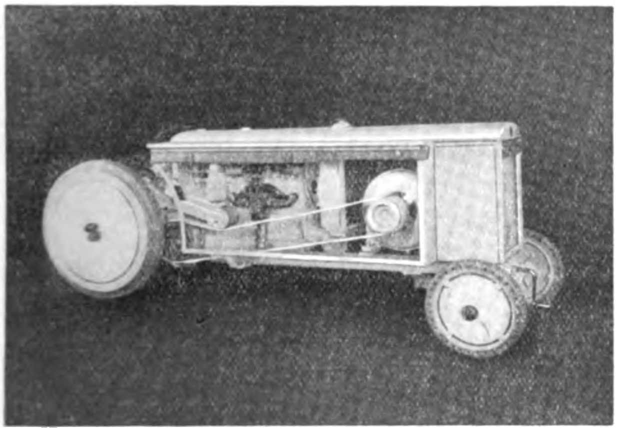

Fig. 62. Fordson Tractor Equipped with 300-amp. Arc Welder

A number of pots used for galvanizing were equipped with electric heat. This equipment ordinarily has a high rate of depreciation due to the dissolving action of the zinc on the container and its distortion due to unequal heat distribution in the heating chamber. With electric units the heat can be distributed uniformly over the surface of the container and by automatic control of the temperature the dissolving action of the zinc is considerably reduced.

The application of electric heat to stereotype pots has been extended rapidly. The first one was equipped in 1925 and there are now over 100 in operation in newspaper plants in all parts of the country; the larger metropolitan dailies requiring 1000 to 1500-kw. connected load for this service.

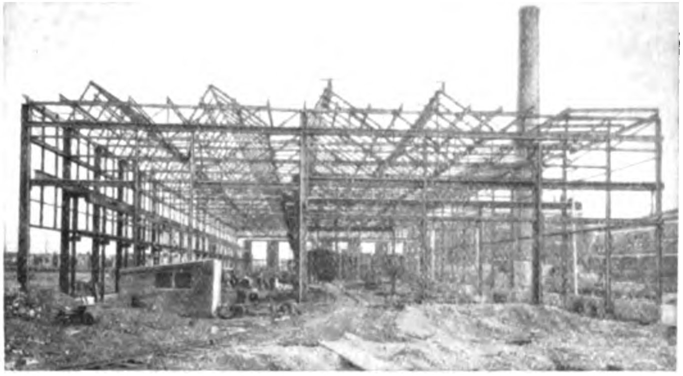

Fig. 63. Framework of Factory Building Assembled by Electric Welding

Furnaces of different types for copper-brazing steel parts together have been in the course of development for several years and are now being used in large-scale operations. By this process a number of separate pieces can be joined into an assembly at one operation, the resulting joints being liquid or gas tight and exceedingly strong. A number of such furnaces (Fig. 65) were installed during the year. An atmosphere containing hydrogen is maintained in the furnace, which excludes air and assists the process in other ways. This process can be adapted to many lines of manufacture, and the furnaces are also suitable for bright-annealing certain metals.

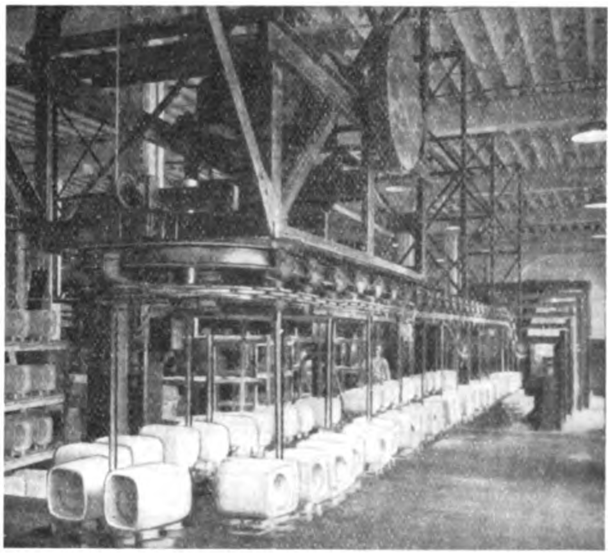

Fig. 64. Electric Conveyor Furnace for Vitreous Enamelling; Energy Required 150-kw., Temperature 1580 deg. F.

ELECTRIC REFRIGERATION

There were no fundamental changes in the design of the household type of refrigerating machine although some minor modifications were incorporated to improve efficiency. One of these was the introduction of an oil conditioner which maintains the oil bath at a temperature which prevents condensation of the refrigerant in the base, thereby maintaining the oil in a state which gives the best possible lubrication.

Another modification was in the float valve which prior to the change was fixed on the box top and which has now been sunk into the box top, thereby insulating the base of the float valve chamber and liquid supply tube.

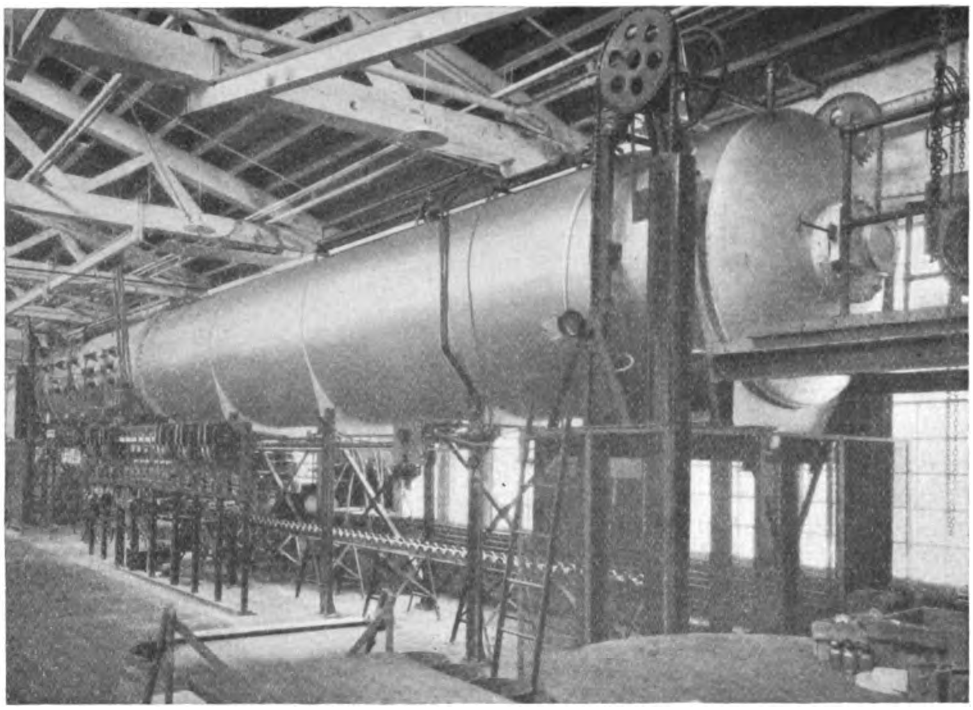

Fig. 65. A Large Continuous Pusher-type of Copper-brazing Furnace 60 ft. Long

The control (Fig. 66) was improved by a device which compensates the overload trip for room temperature and by an attachment which allows the adjustment of the temperature of the food-storage compartment to be made from the outside of the panel.

In order to provide for conditions where space in the household is restricted, a machine was devised in which the compressor unit was modified and mounted with minor alterations on a smaller box top and assembled in a cabinet of 3½-cu. ft. of food-storage capacity.

A new cabinet was also devised (Fig. 67) which consists of an outer shell of essentially one piece, insulated from an essentially one-piece interior with a new type of insulating material. No wood is used in its construction; a special condensate material being used around the door and door opening to join the inner lining to the outer shell. Metal hooks for supporting the food shelves were eliminated.

RESEARCH

The cathode ray was utilized for the first time for the commercial inspection of the materials used in the production of meter jewels.

The cathode-ray oscillograph was provided with auxiliaries such that lightning itself would cause the oscillograph to operate and record the magnitude, time, and frequency of the stroke. This opens up a new field in lightning investigation on power systems and makes possible the duplication of system effects in the testing of lightning arresters and other apparatus.

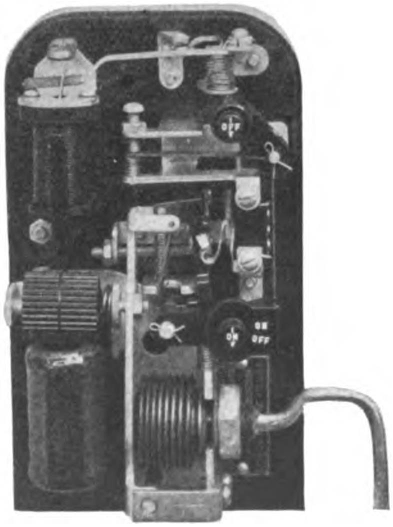

Fig. 66. Improved Control Panel for Household-type Refrigerator with Cover Removed

Vacuum Tubes

A vacuum tube, five inches in diameter and about two feet long, was operated as a self-excited oscillator on a wavelength of six meters. It is capable of radiating from ten to fifteen kilowatts of high-frequency power—probably fifty times as much as any short-wave tube has heretofore been able to radiate. It is connected through a coupling system to a three-meter copper bar which constitutes the tuned aerial circuit.

Several interesting physiological effects have already been noted in connection with the new tube. Medical observations were made of several men placed near enough to the radiating antenna to make possible measurements of changes in body temperature. It was found that the blood temperature rose to nearly 100 deg. F. in about 15 min., after which period the experiment was stopped. It was also found that a salt solution corresponding in strength to blood serum is heated most when placed very close to the high-frequency generator at about 50 million cycles.

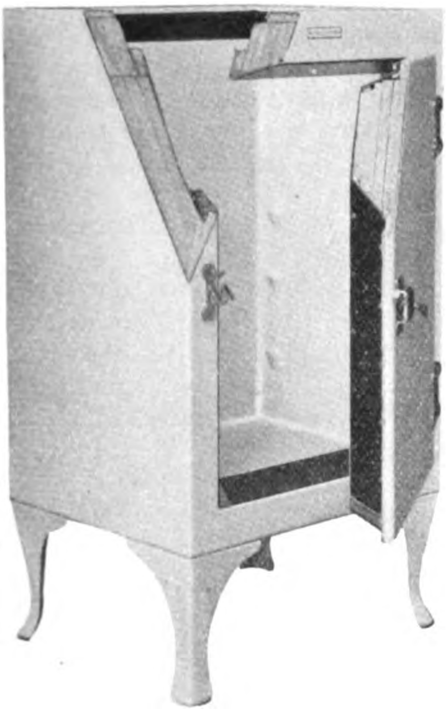

Fig. 67. Improved Type of Refrigerator Cabinet, Showing Arrangement of Heat Insulation

There was a decided increase in the use of screen-grid four-electrode tubes in radio transmitters owing to the fact that a large number of transmitters recently manufactured have been for short-wave operation and require certain wavelength control. Circuit stability and ease of adjustment have always been problems with short-wave transmitters in the past, and the use of the screen-grid tube (Fig. 68) prevents undesired coupling between the different parts of the circuits and thus greatly simplifies the design and operation of these transmitters.

A new form of rectifier tube for relatively high voltages and currents up to 20 amp. is of particular value for obtaining the high direct-current voltage necessary for radio-transmitter operation.

These tubes utilize the electron emission from a coated ribbon filament. A drop of mercury is included in each tube and the anode design is similar to that of the conventional mercury-arc rectifier. In comparison with the high-vacuum type of rectifier tube, this new mercury-vapor tube has the advantages of better regulation and better efficiency, and consequently higher output for a given size of tube.

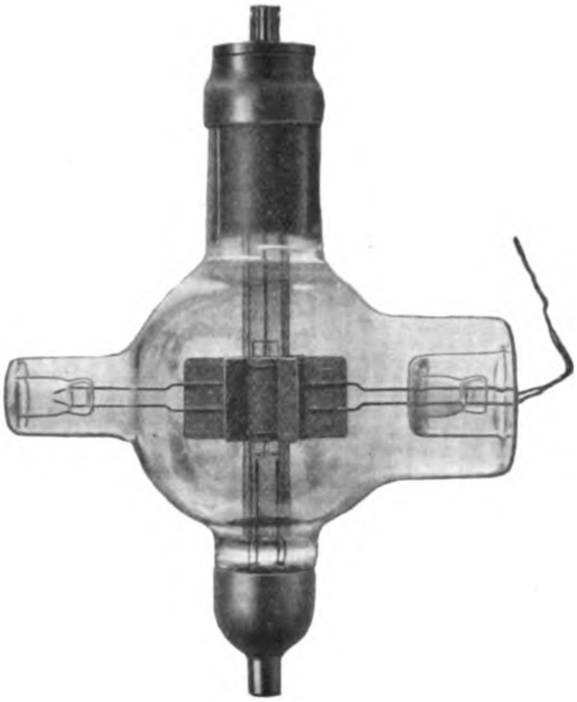

Fig. 68. 750-watt Screen-grid Power Tube

Furnace Temperature Control

A thyratron was adapted to furnace temperature control. The temperature of the furnace is measured by a thermocouple or resistance thermometer connected to the grid circuit of the thyratron in such a way that when the temperature is below the desired point the thyratron carries current sufficient to operate a contactor requiring two or three amperes. In the past very delicate mechanical devices have been used as relays to enable the heavy furnace currents to be controlled by the extremely minute currents from the thermometers. The thyratron supplies the most sensitive relay means yet found for amplifying these feeble impulses to control the large amounts of power used for furnace heating.

Vacuum Fuses

A direct-current vacuum fuse rated 10 amp., 15,000 volts, was produced. It will rupture a current of 45 amp. at that voltage. It consists of a highly evacuated glass tube containing a tungsten filament which is burned out by excessive current. As soon as the burn-out occurs the circuit is open.

It is well known that a direct-current arc at high voltage is very tenacious and difficult to extinguish. However, such an arc is broken in vacuum positively and without any surge at the moment of separation. When the fuse link burns out, one end of the link is hot enough to emit electrons which carry the current shortly after the break takes place. As the point cools down the emission quickly and smoothly falls to zero and the circuit is open without any surge having taken place and in a minimum amount of time.

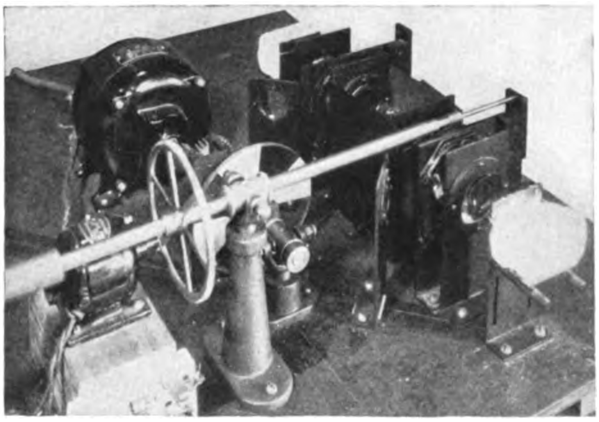

Fig. 69. Arrangement of Spectrophotometer, Showing Location of Magnesium Carbonate Standard

A vacuum fuse for the protection of instrument transformers has a rating of ½ amp. at 13,200 volts. The current which can flow on short-circuit is limited by a series resistance to 110 amp. which current can easily be ruptured by the fuse. Like the direct-current fuse, this device is entirely enclosed so that there is no danger of a discharge being communicated to surrounding apparatus. It opens without surge at the zero point of the current wave, and can be depended upon equally in the cases of a gradual overload which barely exceeds the capacity of the fuse and in the case of a short circuit during which the current reaches the maximum which is fixed by the series resistance.

"Colorimeter"

The exact duplication of any color at any time and at any place has been made possible by the new colorimeter or spectrophotometer which eliminates human judgment, and automatically, rapidly, and precisely measures the wavelengths of colors of any substance. Not only does it measure a color accurately but it makes a record by which it is possible to reproduce it.

The instrument utilizes (Fig. 69) a combination of an optical system and electrical devices whereby the specimen color to be analyzed is illuminated by a ribbon-filament incandescent lamp. Magnesium carbonate, the whitest substance known, is used as the standard of comparison in the laboratory instrument. Light is alternately reflected from the specimen and the magnesium carbonate, and acts upon a photo-electric tube in which it sets up an alternating current.

This current is fed to a vacuum-tube amplifier, the color of the specimen being analyzed as each wavelength of the light spectrum, and the record made automatically by a pen moving over a revolving drum. The light from the incandescent lamp falls perpendicularly on both the specimen and the magnesium carbonate standard and, after reflection from the specimen and standard, enters the slit of an ordinary spectograph system.

Immediately in front of the slit is a rotating glass disk having alternate silvered and transparent segments. The disk is so located that light from the standard enters the slit when a transparent segment is in the beam, and light from the specimen when a silvered segment is in the beam. The spectrograph system disperses the light and a second slit selects the proper wavelength band. Light passing through the second slit falls on a photo-electric tube which receives monochromatic, or single-wavelength, light of pulsating intensity when the standard and specimen reflect different amounts of light in the spectral region.

This pulsating light intensity is changed to a pulsating current by the photo-electric tube, is amplified, and is then employed to run a small motor. This motor actuates a shutter in the beam between the light sources and the standard, and automatically finds a position where the pulsations of the light cease. This position is independent of the characteristics of the photo-electric tube. A pen is attached to the mechanism controlling the shutter to record the reflecting power of the specimen on the rotating drum. A second motor rotates the drum and at the same time drives the slit across the spectrum, thus giving a complete color analysis in less than a minute.

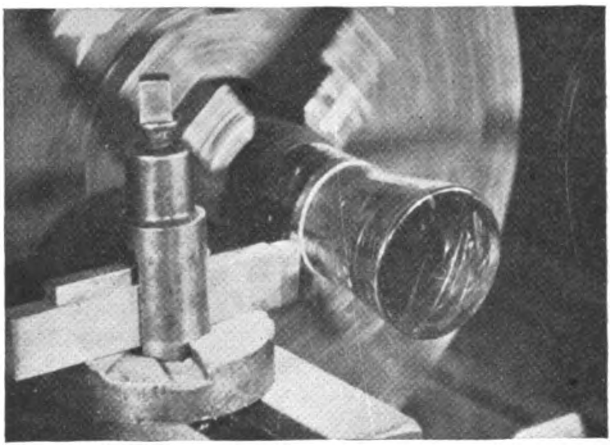

Fig. 70. Carboloy Tool Turning Glass Rod in Lathe

Carboloy

A new tool material, composed of tungsten carbide and cobalt, was developed. The material is extremely hard and the cobalt gives it the strength necessary for cutting tools. This hard metal composition will be marketed under the trade name "Carboloy."

The material is particularly valuable in the cutting of low-tensile materials which are abrasive to the present type of tool, and in this class of work Carboloy tools have been found to be from 25 to 75 times as durable as high-speed steel tools. It can also machine harder and denser grades of steel than can be handled economically by high-speed steel, machine rods of glass (Fig. 70) or porcelain, or drill holes in concrete and rock where it was formerly necessary to use either an expensive diamond drill or a star hammer.

In a comparative test on molded materials containing metal inserts, such as fabric gears used in automobiles, cobalt chromium alloy cutters, which had given the best previous service in this work, required redressing for every 150 parts machined. Carboloy tools under identical conditions finished 11,000 parts before they required resharpening.

When it came to determining quantitatively the hardness of the new cutter, it was found that the usual method of using the Rockwell test could not be used as the point of the diamond wore and crumbled in too short a time if the diamond penetrator were loaded with a weight. It was therefore necessary to use the penetrator without a load. The test showed that common hardened tool steel has an average maximum hardness of 850 on the Brinell scale, that the hardest steel may be taken as about 1000, and that the hardness of Carboloy runs 2000 and above.

The addition of cobalt to the tungsten carbide increases its strength to more than half that of high-speed steel. Tungsten carbide without cobalt has a strength of less than 50,000 lb. per sq. in., Carboloy up to 275,000 lb., and quenched and tempered high-speed steel 425,000 lb.

The material retains its strength and hardness at high temperatures to a remarkable degree and tools made of it have been observed cutting nickel steel when the point of the tool was at a bright, red heat, without showing any ill effects. It has no temper to be drawn by the heat generated.

RADIO TRANSMISSION

A new 5-kw. broadcasting transmitter (Fig. 71) was placed in operation near Toronto (Can.). It is of the master-oscillator power-amplifier type, crystal controlled, and modulation is effected in the output stage

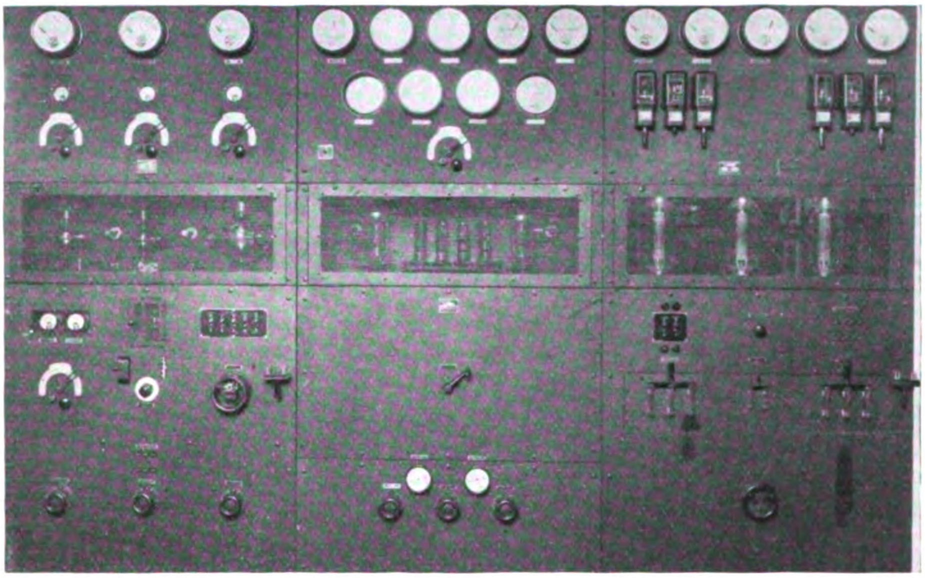

Fig. 71. 5-kw Broadcast Transmitter, Crystal-controlled Amplifier, Modulator-tube Amplifier and Rectifier

With the increased utilization of wavelengths of the order of 14 to 40 meters for long-distance circuits, improved transmitters were produced which meet the more exacting requirements of higher outputs, combined with high-frequency stability and high accuracy of frequency. A number of such transmitters having an output of 20 to 40 kw. were manufactured.

With the availability of the new hot-cathode mercury-vapor rectifying tubes, new circuits were developed with transformers and associated equipment of more conventional design. These factors result in rectifiers of high efficiency and better regulation combined with reduction in weight, size, and cost.

The growing appreciation of the usefulness of short-wave channels resulted in a demand for transmitters having an output of 1 kw. The transmitter designed to meet this demand (Fig. 72) incorporates several new features of circuits and mechanical design. Quartz-crystal control is utilized to maintain a high degree of frequency stability, and four-element tubes are employed which result in greatly simplified controls. A continuous wavelength range from 15 to 50 meters is provided and all controls are readily accessible from the front. A total of six vacuum tubes is used, consisting of the crystal oscillator and three stages of radio amplification. The power supply is obtained from a motor-generator set which provides 1500 and 3000 volts for the plate circuits. These transmitters are being used both in land stations and aboard ships.

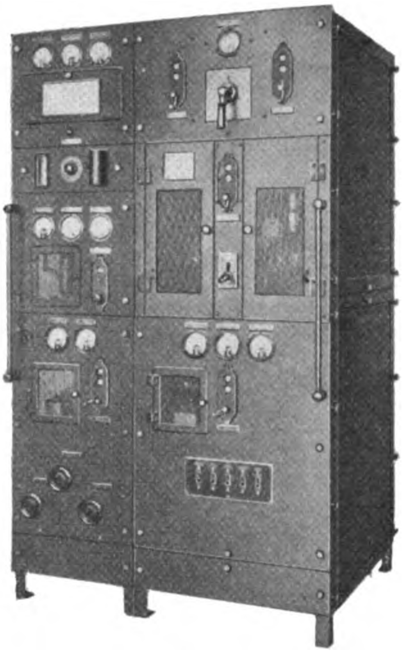

Fig. 72. 1-kw. High-frequency Transmitter Equipment

A transmitter having an output of 25 to 50 watts through a wavelength range of 400 to 1400 meters was developed for use aboard ships, either for emergency or regular communication purposes. Four vacuum tubes are used in a self-rectifying oscillating circuit with 350-cycle plate supply. This arrangement produces a 700-cycle note in the radio receiver, giving a signal which may be received on either oscillating or non-oscillating detectors. For emergency purposes it is not desirable to have the power supply for the transmitter dependent upon the main ship supply and for this purpose the motor-generator which supplies power to the transmitter is operated from a low-voltage storage battery. For those applications in which the transmitter is used for regular communication purposes and for which the power supply on a ship may be used, a design is available for use on 110 volts direct current.

The increasing importance of radio communication as an aid to air navigation created a need for a line of highly-reliable light-weight radio transmitting and receiving apparatus of particularly compact and robust construction for use on the different types of aircraft.

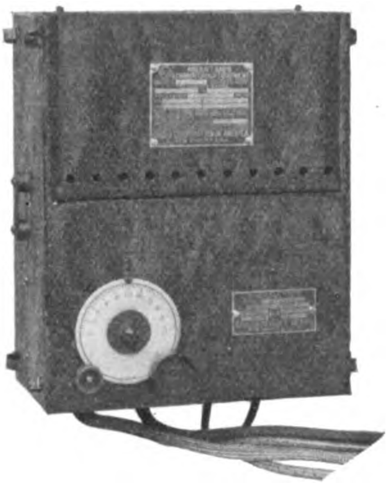

Fig. 73. 10-watt Aircraft Radio Transmitter

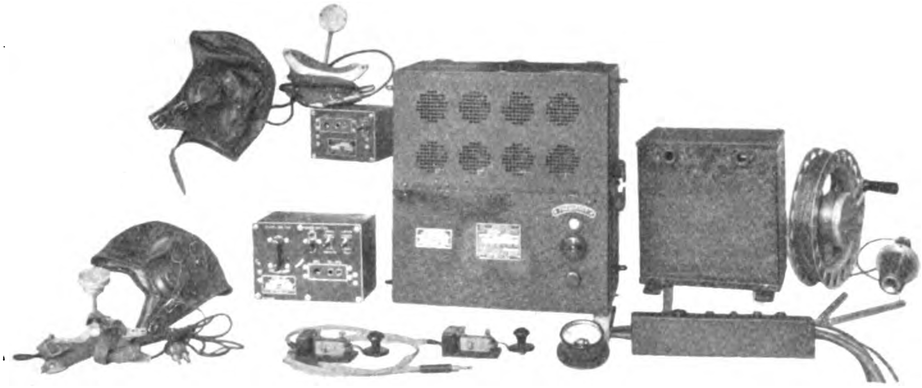

Fig. 74. 300-watt Aircraft Transmitting Equipment

A 10-watt transmitter (Fig. 73) of this type is intended for use on smaller planes and enables the pilot to maintain telegraphic communication at a distance of approximately 75 miles. When the transmitter is used for telephonic signal its range is approximately 25 miles. The weight of the complete equipment with all accessories is 86 lb.

A 300-watt transmitting and receiving equipment (Fig. 74) was designed for use on heavier planes or dirigibles. It weighs approximately 200 lb. and, conservatively rated, will give telegraphic and telephonic communication over distances of 500 and 200 miles respectively.

Developmental Station
W2XAD and W2XAF (Formerly 2XAD and 2XAF)

Decided improvements in the design of high-power broadcasting transmitters were effected by the utilization of recently-developed water-cooled pliotrons having a nominal rating of 100 kw. With two of these tubes in the output stage the transmitter is capable of delivering 100 kw. to the antenna and this power is modulated 100 per cent. This transmitter (Fig. 75) is regularly operated on WGY programs at an output of 50 kw. and a high degree of frequency stability is obtained by means of quartz crystals.

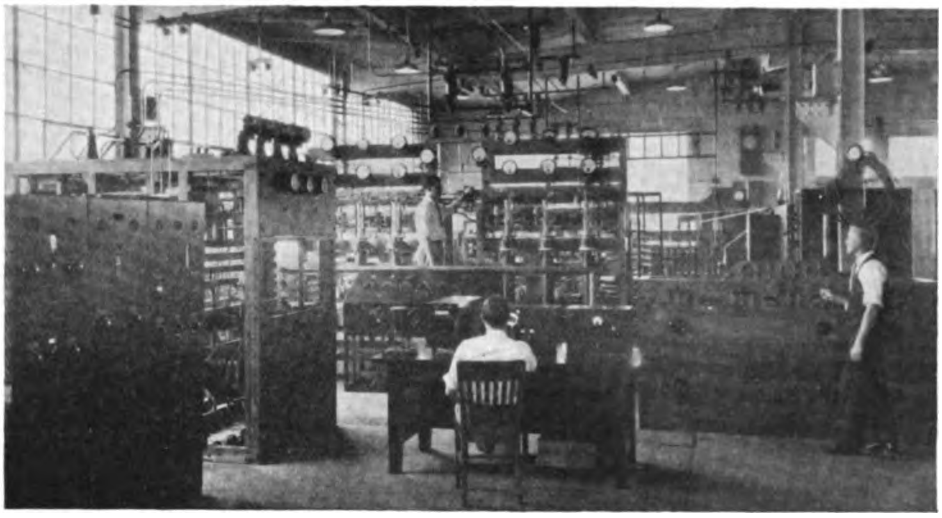

Fig. 75. 100-kw. Transmitter in Operation in Developmental Station

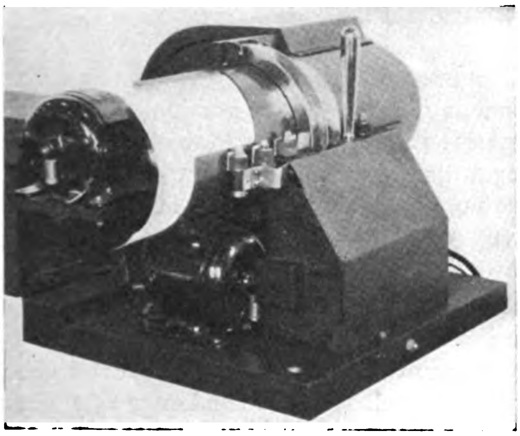

Fig. 76. Continuous Facsimile Radio-telegraph Transmitter

The two short-wave transmitters, W2XAF on 9550 kc. (31.4 m.) and W2XAD on 13,660 kc. (21.96 m.) are in regular operation. These transmitters are operated on alternate nights and broadcast, simultaneously, the same program as that handled by WGY on 790 kc. On special occasions, when programs of international interest are broadcast, both of these short-wave units are operated simultaneously in order that foreign listeners may select the one that affords the more satisfactory reception. The popularity of these two stations with foreign listeners is evidenced by a substantial daily increase in the number of foreign reception reports and comments.

Facsimile Telegraphy

Daily tests of radio facsimile telegraphy were carried on throughout the year between Schenectady and California. Transmitting and receiving apparatus was developed (Fig. 76) by which the ordinary letter sheets of office correspondence can be introduced in the transmitting machine, which is connected with a short-wave radio station. The light reflection from the letters printed on the sheet of paper, intercepted by a photo-electric tube, modulates the radiation from a powerful short-wave transmitter using a new type of projector antenna directed on California. A corresponding machine in San Francisco synchronized with the transmitting machine in Schenectady receives a photographic copy traced by the modulation of the radio wave so that a replica of the original letter may be received a few minutes after the original is placed in the transmitting machine.

CARRIER-CURRENT COMMUNICATION

A new design of terminal equipment, with an output rating of 50 watts, has the external appearance and most operating features similar to previous types but a number of improvements in the transmitter circuit, selective ringing, and mechanical features were incorporated.

A relatively low power unit (Figs. 77 and 78) was developed for use over comparatively short distances.

It has an output of 7½ watts and may be used to communicate with all types of G-E communication equipment as it has the essential operating features possessed by the larger terminal equipments. A rectifier is used to provide direct-current voltages for the various tubes in place of the motor-generators which are used in the larger equipments, and complete control may be obtained over any one of a number of four-wire extensions.

The increased applications of carrier-communication equipments on a number of high-voltage power systems created a demand for a receiver circuit of high selectivity, in order that a larger number of channels or carrier frequencies might be used on a system without cross talk or interference between channels. A filter unit possessing the desired degree of selectivity was developed commercially and may be applied to all previous types of G-E carrier-communication equipments, in addition to being applicable to new equipments.

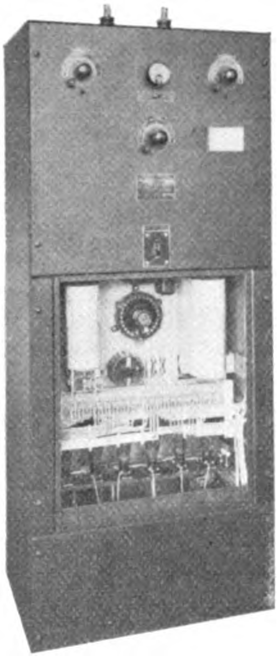

Fig. 77. 7½-watt Carrier-current Telephone Equipment, Front View

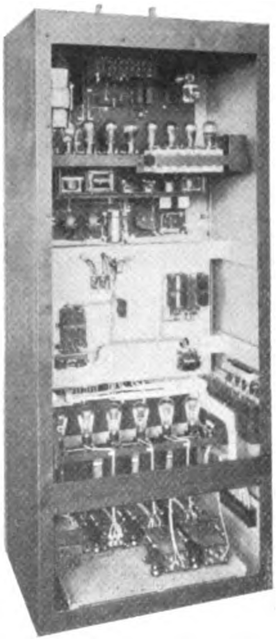

Fig. 78. 7½-watt Carrier-current Telephone Equipment, Rear View

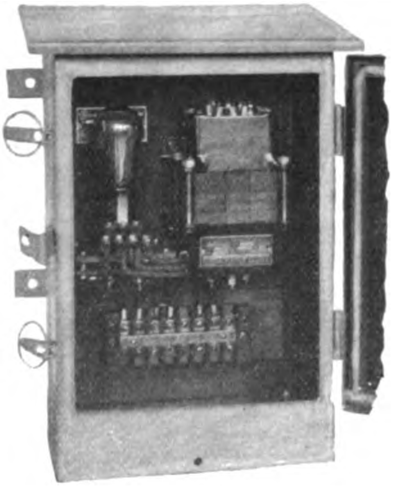

Fig. 79. Outdoor Unit for Vacuum-tube Synchronizing Equipment

VACUUM-TUBE APPLICATIONS

There was an increase in the use of capacitance transformers and vacuum-tube amplifying equipment for synchronizing high-voltage lines. The potential to operate the synchroscope is obtained from the high-voltage lines by means of a capacitance transformer instead of the usual potential transformer. The potential obtained through the capacitance is amplified by vacuum tubes until sufficient output is secured to operate the synchroscope which gives the usual indications of such instruments. The amplifier consists of two stages on each side of the synchroscope. The first-stage amplifier (Fig. 79) is mounted in a weatherproof box near the capacitance transformer. The second stages of amplifier for both sides of the synchroscope are mounted on a switchboard panel which carries also the starting and controlling devices for the motor-generator set supplying power to the entire equipment. The manipulation of this equipment is substantially the same as that required with the customary type of synchronizing apparatus.

Utilizing the essential elements of the synchronizing equipment, with the addition of a relatively small amount of apparatus, an indicating voltmeter equipment is provided. A portion of the output of the synchroscope amplifier is rectified, thereby producing a direct-current voltage which is proportional to line voltage. This provides means to measure the line voltage as well as the indications essential for synchronization.

Equipment was also devised whereby meter readings may be transmitted over telephone lines or by carrier-current superimposed on power lines. By means of a small variable condenser attached to the instrument whose indication is to be transmitted, the frequency of an oscillating vacuum-tube circuit is varied so that the frequency generated is proportional to the instrument indication. This resultant frequency is transmitted to the remote point where it is amplified and applied to a frequency meter. This frequency meter is calibrated directly to indicate the quantity indicated by the remote instrument. Since the magnitude of the reading is proportioned to the frequency, line leakage and resistance do not affect the accuracy of the system.

TRANSFORMERS

The growing demand for the load-ratio control type of transformer is indicated by the fact that about 25 per cent by kv-a. of all power transformers and nearly 40 per cent by kv-a. of all transformers above 20,000 kv-a. are now provided with load-ratio control. Over 2,000,000 kv-a. of G-E transformers so equipped are now in service.

The equipment has been very largely standardized and consists of: two ratio adjusters per phase and intermittent gear mounted inside the transformer tank; two cam-operated contactors per phase, oil-immersed in a small compartment mounted on the outside of the transformer tank; and a driving mechanism with motor, relays, and position indicators mounted in a separate lower compartment. It may be used with single or three-phase transformers, voltages from 15,000 to 73,000, and for currents from 100 to over 1000 amp. Control for circuits of higher voltage may be obtained by the use of series transformers or by placing the control in the grounded end of transformers with a permanently grounded neutral.

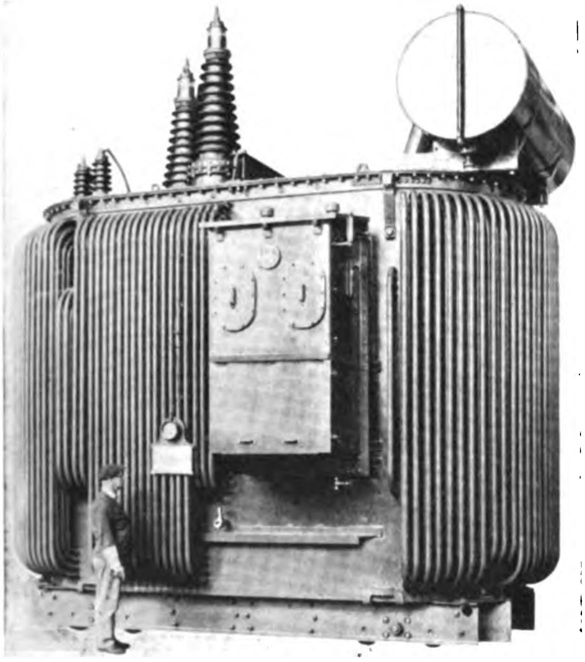

Fig. 80. 20,833-kv-a. Outdoor Transformer, Showing External Casing for Housing Load-ratio Control Equipment

All schemes of load-ratio control involve sufficient reactance to limit the current flow when passing from one tap to another. A separate reactor may be used or the reactance may be inherent in the transformer.

With G-E equipment (Fig. 80) each voltage ratio is obtained directly from a tap, the reactor being short circuited and used only when passing from one position to another. There is no additional no-load loss or exciting current due to the reactor on any operating position and uniform steps in voltage are obtained under all load conditions. For each operating position, two contactors of full-current rating are in parallel, thus affording protection against short-circuit currents, and full-load current is carried without damage if the mechanism should stop on an intermediate position. There are only two contactors per phase, so that circuits external to the transformer tank are minimized.

In recent years, higher and higher line insulation has been used to reduce the number of outages caused by lightning. Until recently, this higher line insulation has sometimes been extended right up to the station or transformer bank without providing adequate protection to the station or apparatus in the station.

Considerable attention has therefore been given to coördinating the lightning insulation strength of transformer windings, the lightning arc-over of transformer bushings, and the lightning arc-over of adjacent transmission-line insulation. The need for this is evident since the maximum lightning voltage that can reach the station is dependent upon the length of the insulator string next to the station and not upon the normal circuit voltage.

The transformer and insulator string form an insulation chain and obviously it is not logical to make the transformer the weakest link in the chain, when it should be the strongest.

Even in cases where lightning arresters are used, proper coördination is advisable. The arrester if properly installed will keep the lightning voltage below the arc-over voltage of the line insulation and will not only serve to protect the station apparatus but will reduce outages and improve service. However, in case the arrester should be temporarily disconnected or should not be properly installed it is essential to have present a "last line of defense." This can be the transformer bushing or a string of insulators, or a horn-gap whose lightning arc-over voltage is slightly lower than that of the bushing. It is, of course, undesirable to have transformer bushing arc-overs. This can be prevented by providing insulator strings over a given distance, generally several poles or towers away from the station, or a single spill-way gap within a few feet of the transformer bank, the arc-over voltage of which is less than that of the transformer bushing.

The following levels of insulation will give maximum protection: standard or higher insulation on the main part of the line; standard insulation or the equivalent in the form of a gap in the vicinity of the station; transformer bushing stronger than the standard line insulation; and transformer windings stronger than the bushings.

Where the line insulation in the vicinity of the station is increased above standard, other levels of the insulation chain should be correspondingly increased.

The efficiencies of modern transformers are so high that new records are rarely made. During the year, however, two 20,000-kv-a. units attained a full-load efficiency of 99.52 per cent.

Electric brazing was adopted to eliminate, as far as possible, the use of soldered joints in transformer construction. The brazing consists of assembling the two current-carrying parts with a piece of silver solder between them and then raising the parts to a red heat by passing a heavy current through them. Joints thus made are far better, mechanically and electrically, than soldered joints This method is suitable for even large size units, four 40,000-kv-a. transformers being built with all joints electrically brazed.

There were under construction two single-phase self-cooled 28,866-kv-a. 220,000-volt transformers, the design of which is notable in that these units will be insulated for and tested at 500,000 volts.

A 25,000-kv-a. load-ratio control transformer, now under construction, will be provided with self-cooled, forced oil, and oil air-pressure features, so that, when required, the capacity can safely be increased to 35,000 kv-a.

An 83,333-kv-a. 3-phase 25-cycle, water-cooled auto-transformer was completed for the Buffalo General Electric Company. Its kilovolt-ampere output is probably the maximum ever concentrated in one transformer unit; and based on its equivalent transformer capacity of 49,200 kv-a., it requires parts that could be used to build a 60-cycle two-winding transformer rated about 100,000 kv-a. at the same voltage.

It occupies a floor space of 23 ft. by 14 ft., stands 14 ft. high (Figs. 81 and 82) and when filled with 13,300 gal. of oil it weighs 165 tons. It has 1½ miles of copper cooling coil arranged in four layers and 20 sections, and when operating at full load it requires 190 gal. of water per minute.

In order to limit the current that can flow during a short-circuit on the system, the high-voltage winding consists of two separate circuits, each of which will be connected to a separate section of the station bus. Each circuit is designed to carry not only half the total load, or 41,667 kv-a., but also under unbalanced conditions a maximum of 55,000 kv-a. with the load on the other circuit not to exceed 28,333 kv-a.

Two three-phase air-blast transformers, greater in kilovolt-ampere capacity and larger physically than any so far produced, were completed for the Waterside Station of the New York Edison Company, where they will operate in connection with a 40,000-kw. induction-synchronous frequency-changer set. Each unit is rated 25 cycles, 18,500 kv-a., 11,800/3300/440 volts.

They are of shell-type design (Fig. 83) with rectangular coils, a construction used to distribute the cooling air at high velocity correctly throughout the windings and core. Despite their exceptional capacity, these transformers each occupy a floor space of only 6½ by 11 ft.

Rectifier Transformers

Transformers for mercury-arc power-rectifier service, in addition to the ordinary function of changing the voltage and current to the required values, are used for phase transformation so that a larger number of phases than the usual three or two are available. In some cases, they serve also to subdivide the current into a number of independent circuits.

The use of a common cathode in the rectifier with a number of anodes makes it necessary to use two anodes for each phase with half-wave current in each, and this necessitates an even number of phases in some form of star connection with the negative direct-current line connected to the neutral and the various anodes to the points of the star. The half-wave secondary current necessitates a secondary kilovolt-ampere capacity 41 per cent in excess of that of the primary.

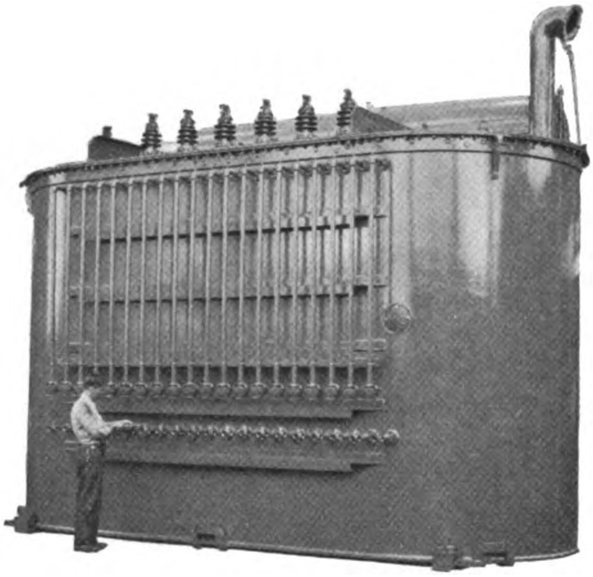

Fig. 81. 83,333-kv-a. Outdoor Auto-transformer for Buffalo General Electric Company

The voltage regulation of a rectifier installation is largely a function of the transformer with which it is used because the voltage drop in the mercury arc is very nearly constant throughout the usual range of load. Most of the drop due to the transformer is caused by the leakage reactance which cannot be reduced beyond certain limits without jeopardizing the equipment in case of a short-circuit. As the regulation of such a star-connected rectifier circuit having a large number of phases is much greater than one with a few phases, it is customary to use two or four three-phase stars in a single transformer and to connect their neutrals through an interphase transformer which forces them to act as independent three-phase rectifiers with consequent good regulation. By arranging these circuits in six-phase or twelve-phase relation, the advantages of the large number of phases may be retained.

The leakage reactance which is the cause of voltage regulation is that of each individual secondary phase; consequently, it is essential to so interlace the secondaries that each phase will bear a reasonable and normal relation to the primary windings without reference to the remaining secondaries. Moreover, the characteristics of these secondary phases must be substantially identical and their relation to the primary symmetrical if additional harmonics due to unsymmetrical leakages are to be avoided under load.

If certain limits of temperature or pressure in the vacuum chamber are exceeded, the mercury-arc rectifier may "arc back," thus imposing a short circuit on the secondary of the rectifier transformer. The subsequent extinguishment of such a reverse arc may be sufficiently abrupt to cause a severe voltage surge within the transformer. As a result it is necessary to insulate between turns and between the various secondary phases for voltages somewhat out of proportion to the voltage of the direct-current circuit to which the device is connected.

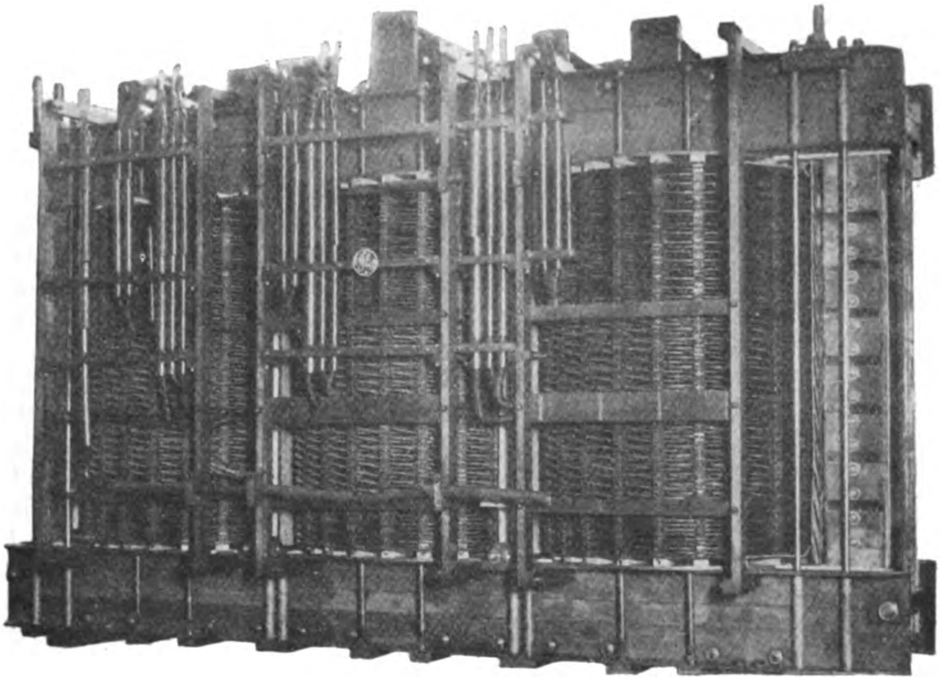

Fig. 82. 83,333-kv-a. Transformer, also Shown in Fig. 81. Internal view from low-voltage side

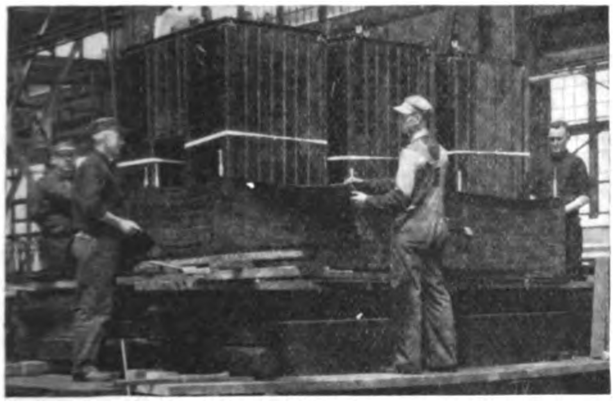

Fig. 83. Assembling Core of 18,500-kv-a. Shell-type Air-blast Transformer

These requirements of phase multiplication, close symmetrical interlacing, and high insulation are necessarily conflicting and are the chief reasons for the complexity of rectifier transformers. The problem of phase multiplication may be in part transferred to the primary winding, but it is generally considered desirable to confine the complications to the secondary and retain the advantages of a simple three-phase primary winding for connection to the high-voltage lines.

Testing Equipment

The coronaphone is an instrument which was developed for the detection of any incipient trouble in a high-voltage transformer by means of noise tests.

It is known that various types of insulation trouble have their characteristic noise. Under operating conditions a transformer may emit a complex noise, some being the normal hum and the remainder being noise caused by some internal trouble.

By the use of the coronaphone (Fig. 84) the normal hum is filtered and suppressed, while the remaining noise is amplified and is used either to listen to or to operate a relay. The instrument consists of a "detector" which is attached to the outside surface of the transformer tank; a "filter" to suppress the normal hum; and a "head phone" or a "relay" to detect any incipient trouble.

The voltage available in testing laboratories was increased by the construction of an artificial lightning generator capable of delivering 3,600,000 volts or more than 15 times the potential of the highest voltage transmission lines now in commercial service.

The consistent increase in voltages available (Fig. 85) makes it possible to work with full-size transformers and transmission lines, and to secure data which will permit the design of higher potential equipment for commercial circuits when the demand for higher voltages arises. The knowledge already secured has been incorporated in the design of both transformers and protective apparatus.

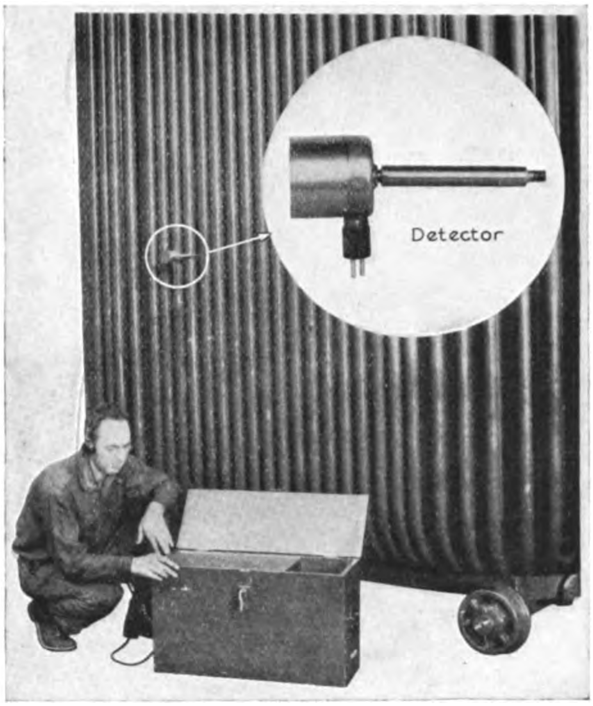

Fig. 84. Using the Coronaphone to Detect Incipient Corona in Transformers

It is interesting to note that the results obtained with these higher voltages conform in all essentials to those obtained at lower voltages and also in a large degree confirm earlier calculations made on a theoretical basis.

The 2,100,000-volt transformer set in the Ryan High-tension Laboratory at Stanford University (Fig. 86) has now been in service for two years, during which time a number of important investigations on full-size transmission line sections have been carried out.

One of the first tests made was on a 240,000-volt full-size transmission line tower on which a complete three-phase test was made at 700,000 volts to ground and 1,200,000 volts between lines. Further investigation was made in regard to the characteristics of the space charge that surrounds a conductor in corona, a study of high-voltage flash-overs during which oscillographic records were secured of voltages and currents both before and during the flash-over, the maximum flash-over range being 30 ft. in length.

Sphere-gap and point-gap arc-over voltages were determined by direct measurement utilizing current passed through a water-resistor and recorded on an oscillograph. Over a million volts to ground were measured in this way with an accuracy believed to be better than 98 per cent. Some of the more recent activities include experimental work on a million-volt outdoor transmission line using conductors of 1, 2, and 4-in. outside diameters.

This testing equipment generates its high potential at commercial frequencies.

Instrument Transformers

A cable-type capacitor for carrier-current coupling was combined with a current transformer for metering purposes. The double-conductor concentric cable with the two conductors in series forms the two-turn primary winding which is placed in series with the high-voltage circuit. A modified two-stage current transformer (Fig. 87) is mounted upon the cable at the bottom of the loop and, by special design, instrument transformer accuracy is obtained on single-stage watthour meters.

Above the transformer is mounted the pressure reservoir which maintains an oil pressure in the cable and the bushing. A limiting horn-gap is mounted under the metal cover on the supporting frame. A short-circuiting switch for the supporting insulators is provided for grounding the frame. Both 110 and 132-kv. outfits of this type were built.

A 75,000-volt oil-filled cable terminal was designed for mounting in the oil-filled junction box of a 66,000-volt transformer. The lead-covered cable enters the terminal from below, and the lead sheath is sealed to the wiping sleeve with the customary lead wipe. A sheath insulator of moulded compound immediately above the wiping sleeve provides insulation between the sheath and the grounded support of the terminal.

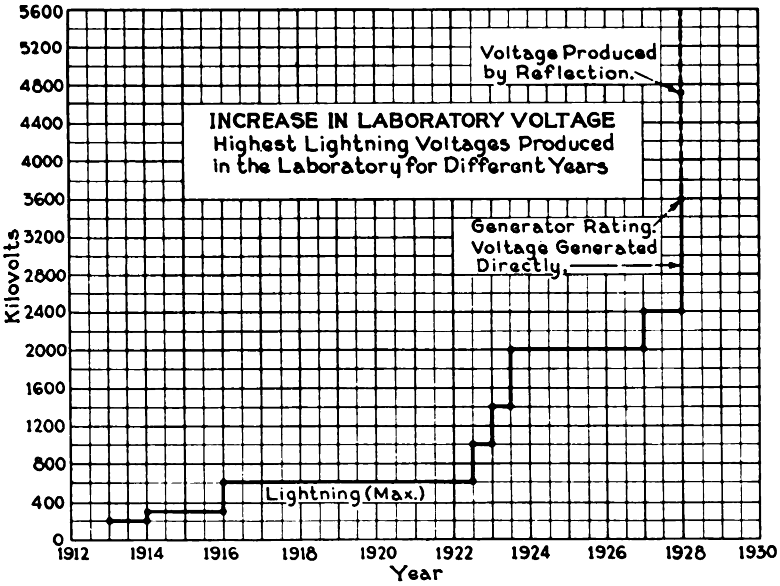

Fig. 85. Increase in Available Lightning-generator Voltage

Surrounding the cable, immediately above the sheath insulator, is the housing (Fig. 88) for a bushing-type current transformer. The entire terminal, including current-transformer housing, is filled with oil maintained under pressure by a combination-type oil reservoir.

Distribution Transformers

A vital element in the operation of network systems is a satisfactory design and arrangement of cable disconnecting and grounding switches for network transformers. During the year, there was a definite trend toward the inclusion of these elements in external pot-heads even for small units. The details of the switching elements were also improved (Fig. 89) so as to render them free of alignment troubles and readily removable for inspection or repairs. The insulation was also increased and safeguards against improper operation provided.

While these are detail improvements, they are of definite value in the more efficient handling of networks and their improved factor of safety is of great importance to the practical operator.

REACTORS

A single-phase 60-cycle 2800-kv-a. oil-immersed type of reactor was designed to sectionalize a 120,000-volt bus of a large generating station. Six 75,000-kv-a. generators are connected to this bus through transformers. These reactors are probably the first to be built for 120,000-volt service and on account of the high voltage and great kilovolt-ampere capacity are the largest of the oil-immersed type so far constructed.

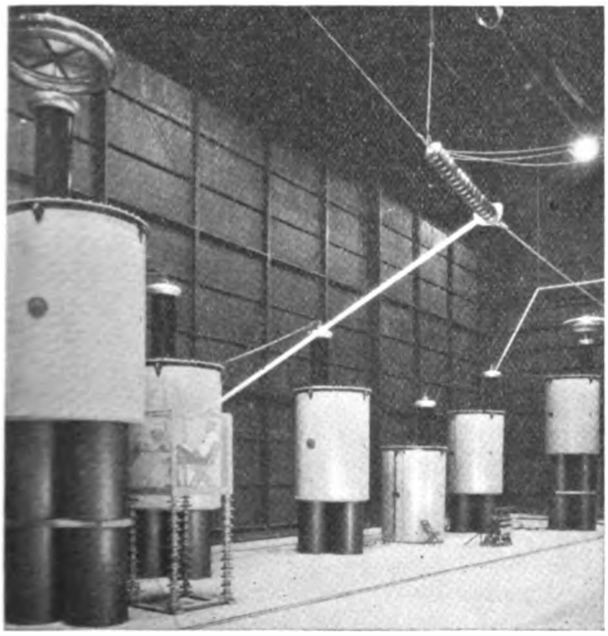

Fig. 86. 2,100,000-volt Transformer Testing Set in Ryan Laboratory, Stanford University. Note operator at left in insulated cage

The windings are wound on thick Herkolite cylinders (Fig. 90) which fit in grooves in the top and bottom clamping plates. The windings are spaced from the clamping plates by heavy Herkolite end rings which provide high insulation from the winding to the clamping structure and have great mechanical strength with which to transmit the clamping pressure to the winding. The clamping plates are drawn securely against the end rings by non-magnetic studs having an elastic limit of 60,000 to 70,000 lb. per sq. in. Four of these studs screw into the bottom of the tank and hold the winding rigidly in its place.

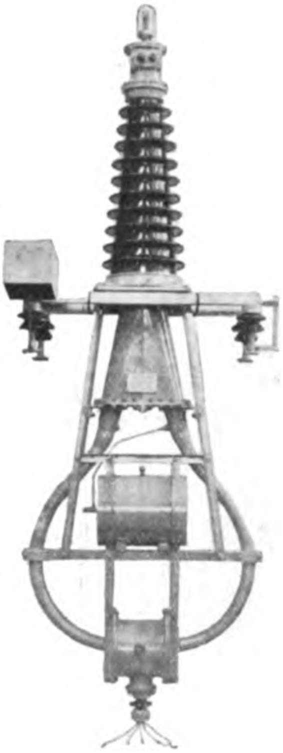

Fig. 87. Combination Coupling Capacitor and Current Transformer

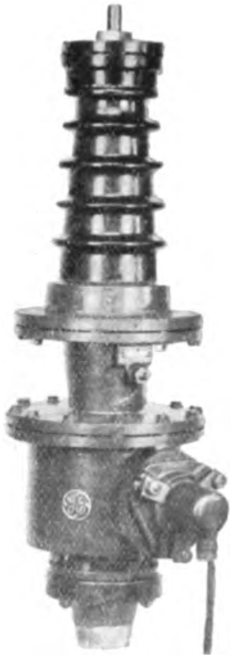

Fig. 88. Cable Terminal Provided with Current Transformer for Metering Purposes

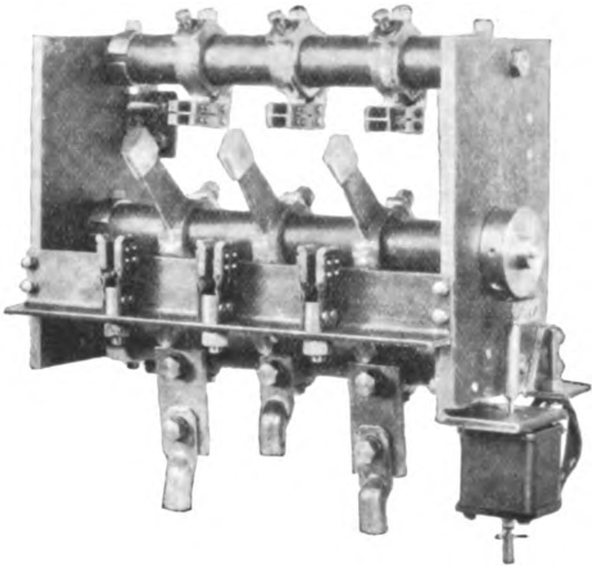

Fig. 89. High-voltage Grounding Switch for 3-phase Subway Service on Network System Transformers

With a short-circuit on one section of the bus, the current from the generators connected to the other section must pass through the reactors and is limited by them to eight times the normal current of one generator.

CAPACITORS

The first installation of series capacitors for compensating the inductive reactance of a transmission line has been in successful operation in the lines of the New York Power and Light Corporation at Ballston (N. Y.), for approximately ten months. It consists of three 415-kv-a. single-phase outdoor-type series capacitor units which are connected in a 20-mile 33-kv. 7500-kv-a. 3-phase line. During this period, the equipment has been subject to usual operating conditions incidental to line switching, faults on the line, and about the average number of lightning storms. No trouble has been experienced, either with the individual capacitor units or the protective equipment.

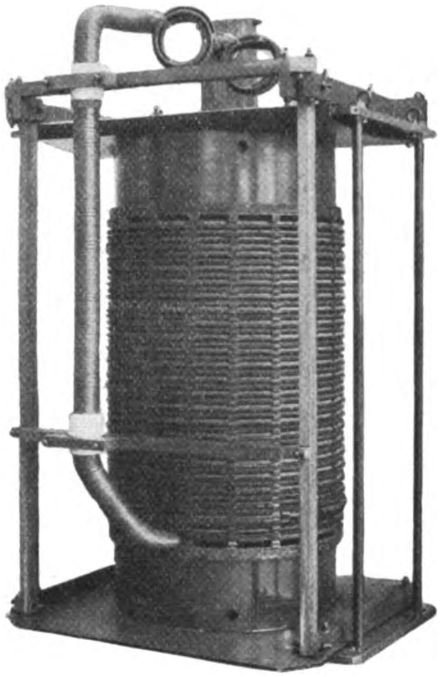

Fig. 90. Oil-immersed Type Reactor for Use on a 75,000-kv-a. 120,000-volt 3-phase Circuit

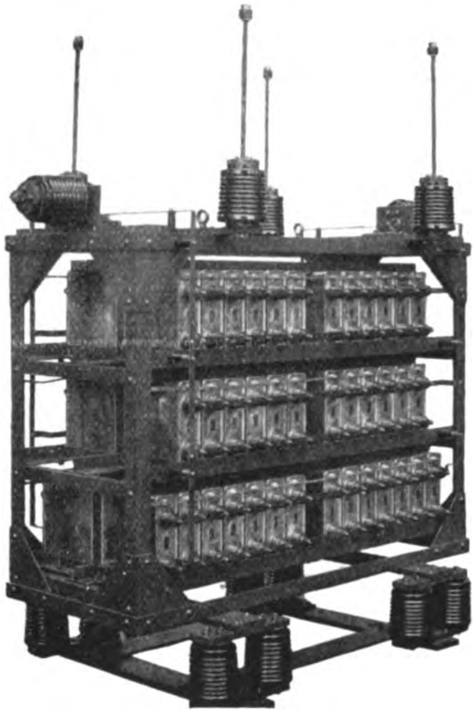

Fig. 91. Internal Rack Assembly (removed from tank) of 415-kv-a. 3170-volt Single-phase Series Capacitor for Transmission-line Regulation

The theory involved is quite simple. A capacitance placed in series with a reactance can be made to compensate for the reactance if $\frac{1}{2\pi fC}$ is made equal to $2\pi fL$.

For such a circuit the potential drop across the capacitor for all values of current is equal and opposite in phase to the potential drop across the reactance. If this circuit is a transmission line, only the drop due to the ohmic resistance of the line affects the regulation of the circuit. Therefore, by the use of properly compensated circuits, the approximate equivalent of direct-current transmission may be obtained and all the advantages of transmission by alternating current retained.

In the practical operation of the series capacitor (3) the capacitor element (Fig. 91) must be insulated from ground for line potential and the dielectric between capacitor plates so proportioned as to stand the potential drop across the capacitor due to normal full-load line current. Under short-circuit conditions, when the current increases and abnormal drop develops across the capacitor, the protective equipment limits the short-circuit current to the same value as would result without the series capacitor; *i.e.*, by the compensation of the inductance of the transmission line and transformer, the impedance of the circuit is lowered, but the protective device instantaneously removes the series capacitor from the circuit, thus retaining the advantage of limitation of short-circuit current by inductive reactance. In fulfilling the current-limiting function, the protective equipment also limits the potential rise which can occur across the capacitor. Thus, if the normal drop were 10,000 volts, then ten times the normal current on short-circuit gives 100,000 volts across the capacitor from which the capacitor is protected. This is accomplished by the removal of the capacitor from the circuit on the rise of short-circuit current by means of a sphere gap and high-speed contactor.

At the present time, it appears that the series capacitor will come into general use for: automatic regulation of transmission voltages, increasing the power limit of transmission lines, or as compensation for all or part of the reactance in a line so that it will share its proper division of load when paralleled with another transmission line of different characteristics.

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(3) "The Series Capacitor Installation at Ballston, N. Y.," by E. K. Shelton, GENERAL ELECTRIC REVIEW, Aug., 1928, p. 432.

A group of six cable-type capacitors (Fig. 92) with Herkolite cylinder supports were utilized in connection with a 1,500,000-volt lightning-generator equipment for Leland Stanford University. Each of these capacitors contains about 100 ft. of oil-filled hollow-core lead-covered cable, the two ends of which are brought together and terminated in an oil-filled porcelain bushing. Protective hemispherical gaps limit the voltage which can be applied to each unit. The six units are used in combination with three chain-connected transformers.

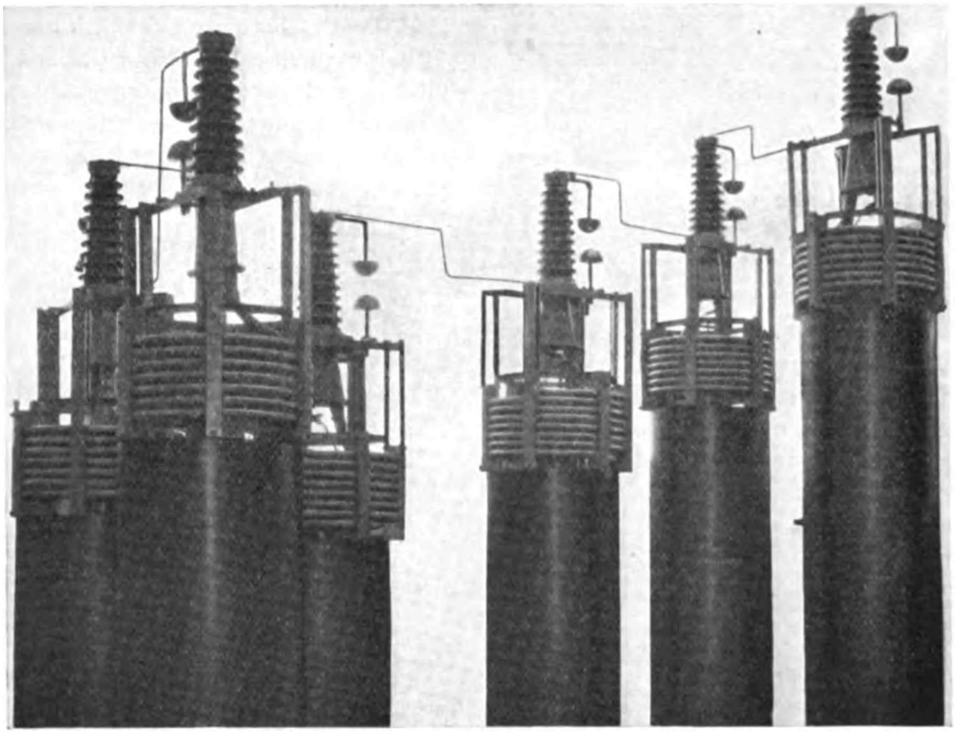

Fig. 92. Six 110-kv. Oil-filled Cable-type Capacitors Connected in Series

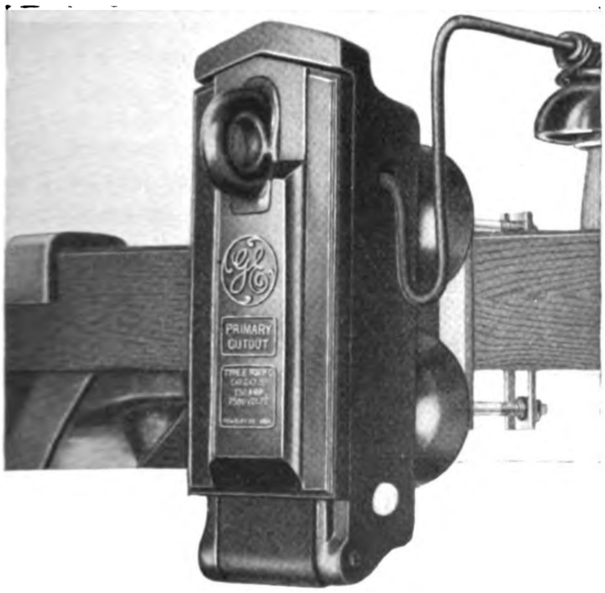

Fig. 93. 150-amp. 7500-volt Primary Cutout with Rated Interrupting Capacity of 3000 Amp. at 60 Cycles

CUTOUTS

Four new primary cutouts were produced with housings of the highest-quality wet-process porcelain (Fig. 93), giving them a dielectric strength comparable with the high insulation now being used on modern distribution systems. High interrupting capacity was obtained, without increasing the physical size, so that this type of expulsion cutout can now be used on systems subject to severe short-circuits.

The stationary contacts are held by spring pressure into recesses in the side of the porcelain housing. This new method has eliminated the use of babbitt or cement for holding such fittings and provides maximum insulation strength through the back of the housing and, being flexible, assists in the self-alignment of the contacts.

In order to increase the safety to the lineman and to minimize the accumulation of static charges, all metal parts such as hinges and latches, with the exception of the hanger, were omitted from the exterior.

CONDUCTOR CABLE

The 132-kv. single-conductor oil-filled cable lines put in service by the Commonwealth Edison Company of Chicago, June 2, 1927, and by the New York Edison-United Companies, August 9, 1927, have operated with no electrical failures.

The success of these installations led to the development of three-conductor oil-filled cable and a small 33-kv. installation was put into service on October 2, 1928, by the Commonwealth Edison Company of Chicago.

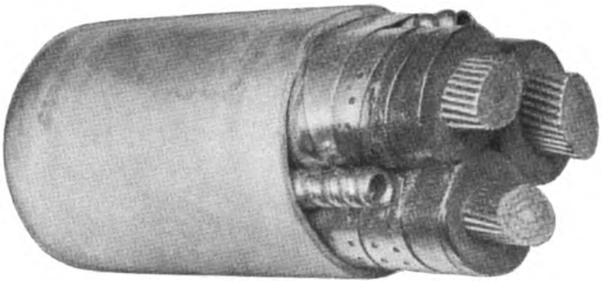

Fig. 94. 33-kv. 3-conductor Shielded-type Oil-filled Cable

This cable (Fig. 94) is of the shielded-conductor type, but the usual side and center fillers are omitted, these spaces being used as oil ducts. Copper ducts in the form of conduit are inserted in the side filler spaces to form oil ducts and to support the lead sheath. This type of cable permits, on account of the thinner insulation required than formerly, an increase of approximately 50 per cent in the copper area for a given sized duct.

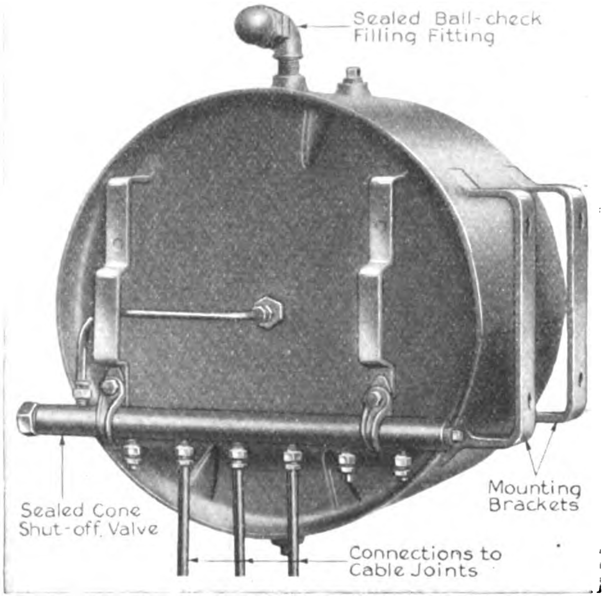
Sealed Ball-check Filling Fitting
Mounting Brackets
Sealed Cone Shut-off Valve
Connections to Cable Joints

Fig. 95. Steel Cell-type Pressure Reservoir and Manifold for Oil-filled Cables

The long-time vacuum and re-impregnating process used in installing the 132-kv. oil-filled cable in the field were eliminated in this three-conductor cable installation by shipping the cable full of oil and installing it without draining out the oil.

The joints used for connecting the cables are of a new type having semi-stops in each end to prevent the flow of oil freely from one section of cable to the adjacent sections. Since there would be some leakage of oil through the insulation under differences of pressure on opposite sides of the joint, a new principle in oil reservoirs was used. This is known as the "balanced-pressure" reservoir system. Each reservoir is adjusted as to pressure-volume characteristics according to the length of cable to which it is connected so that all the reservoirs connected to the cable work in unison, thus maintaining equal pressures on each side of the joint.

Since all three conductors are enclosed in the single-lead sheath, there are no sheath losses.

This type of cable can be utilized for circuits up to 66 kv. and should be especially useful where the amount of power per circuit does not warrant the installation of three large single-conductor cables or where a multiplicity of circuits is desired.

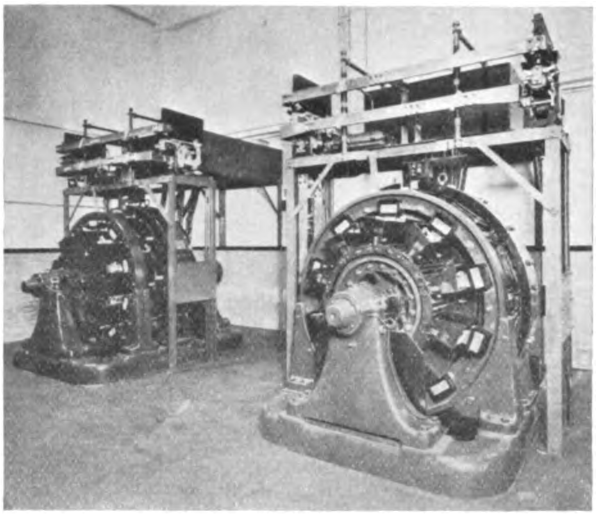

Fig. 96. Typical Arrangement of Synchronous Converters for Railway Service with Special Mounting of High-speed Circuit Breakers

The use of cable joints filled with thin oil and of some form of oil reservoir to feed the joints and cable has become almost universal on cables operating above 20,000 volts. A small reservoir of the same type as the pressure reservoirs used on the oil-filled cables was developed (Fig. 95) with pressure elements consisting of gas-filled metal cells enclosed in a tight oil tank. Since the gas is an elastic medium and the cell walls are thin, the reservoir pressure follows the expansion and contraction of the oil in the cable due to temperature changes. Thus a positive pressure is maintained in the joints at all times and pressures below atmospheric cannot persist in the cable for any great length of time. The cable insulation is, therefore, protected against ionization to a large extent and leakage of air or moisture into the joints is prevented.

An interesting installation of 45-kv. single-conductor cable was made by the New York Edison Company in an outlying district near Yonkers. Three single-conductor lead-covered cables (without armor) were buried in a trench about 2 ft. deep, dug about 1 ft. from the edge of a macadam road. The three cables are bedded in a layer of screened loam and clay and are covered by concrete slabs to protect them from mechanical injury. The sections are 1000 ft. long; small splicing chambers being used to contain the splices and cell-type oil-pressure reservoirs. This cable line has been in successful operation for nearly a year.

AUTOMATIC STATIONS

Railway Substations

Automatic control for railway substation equipment was chosen by a number of operators during the year in preference to manually operated equipment. It is now generally recognized that in addition to savings in the cost of operation, due to reduction in the operating personnel, the automatic switching apparatus also furnishes economies and dependability which are not ordinarily obtained with attended stations.

One of the most conspicuous examples of automatic control will be found in the substations of the Cleveland Union Terminals Company which is equipping the electric zone around the new Cleveland Terminal. These stations will be the first in the United States to use 3000 volts direct current with automatic control. Each motor-generator set is of 3000-kw. capacity, to provide sufficient power for the heavy main-line movement of passenger trains through the city of Cleveland.

The track feeders will be equipped with high-speed breakers (Fig. 96) and the entire system will be under the supervision of a dispatcher located in the Terminal Building. The synchronous-selector type of supervisory control will be used to accomplish this result.

Another important project is the conversion of the present distribution equipment of the Northwestern Pacific Railroad to automatic control. Three stations are being equipped; one with a 1500-kw. synchronous converter, one with two 1000-kw. synchronous converters, and a third with a 1000-kw. synchronous motor-generator set which is now operating in an existing station.

Two other installations are also of interest. One of these is a two-unit station being installed by the Mitsui Company for Ise Tetsudo K.K. in Japan to supply power to a 1500-volt direct-current electrification, using two synchronous converter sets each consisting of two 500-kw. 750/1500-volt units.

The Honolulu Rapid Transit Company is adding automatic equipment for supplying the city railway system by means of two 1000-kw. synchronous converters completely equipped for automatic operation.

A number of important mercury-arc rectifier installations (Fig. 97) made during the year are using automatic control. The Piedmont and Northern Railway with two 750-kw. rectifier units is supplying 1500 volts for the operation of an extensive traction system. These units will be completely automatic.

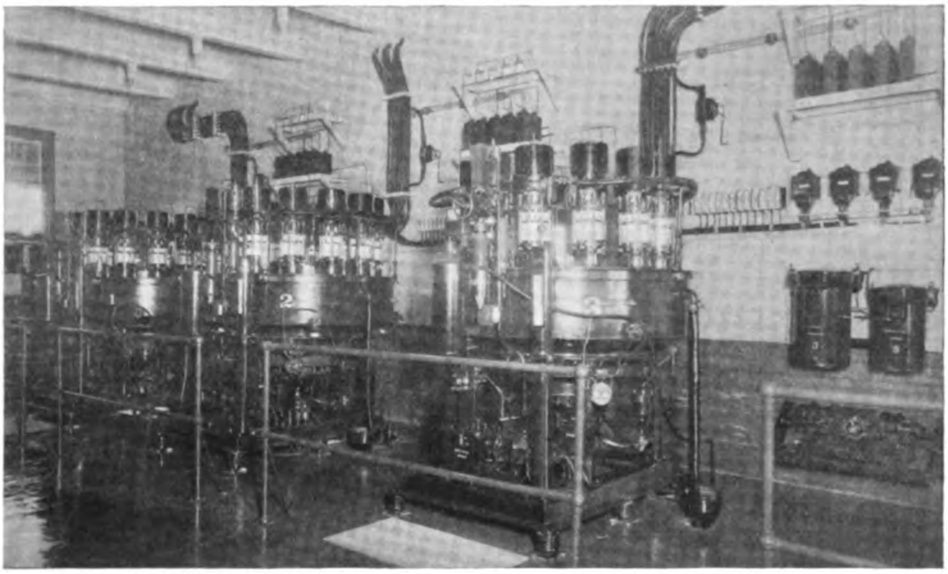
Fig. 97. Typical Arrangement of Mercury-arc Power Rectifiers for Railway Service, Showing Three 1000-kw. 12-anode 650-volt Rectifiers

The Columbus Railway Power and Light Company which has been operating a 1000-kw. 600-volt rectifier unit for some time with manual control is now installing one 500-kw. rectifier in each of two other stations with complete automatic control for each unit. These units will be required to operate in parallel with synchronous converters.

In connection with the Chicago, South Shore and South Bend Railroad, which has been operating several rectifier stations with automatic equipment for a number of years, additional units are being installed (Fig. 98) including two 750-kw. rectifiers in existing stations which will be provided with automatic control.

The Lamont Substation of the Chicago and Joliet Electric Railway, equipped with a 500-kw. 600-volt rectifier, has now been in operation for several months and is an important factor in the complete modernization of this property.

Other notable automatic substation equipments placed in service on various railways during the year include nineteen stations supplying power to the Cincinnati Street Railways, the Harmon and Hastings Substations of the New York Central Railroad (the former equipped with two 2500-kw. synchronous converters and the latter with one similar unit), and ten substations on the Sacramento Northern Railways which were put into operation this year, making a total of thirteen automatic substations on this road. A 4000-kw. synchronous converter was being installed by the New York Rapid Transit Company at the close of the year.

Automatic mercury-arc rectifier installations were completed by the Philadelphia Rapid Transit Company, the Los Angeles Railway Corporation, and the Pacific Gas and Electric Company.

Hydroelectric

The St. Lawrence Valley Power Corporation put into progress the installation of a three-unit automatically-controlled hydroelectric station which includes full automatic synchronizing. Two of the machines are rated 1375 kv-a. each and the third 625 kv-a. The two larger units make use of a common synchronizing equipment while the smaller unit has an individual one.

The 100,000-kv-a. automatic station of the Louisville Gas and Electric Company (Fig. 99) was placed in service. It is the largest automatically controlled hydroelectric station. The present installation consists of eight 12,500-kv-a. vertical-shaft generators operating at a terminal voltage of 13,800. Space is provided on the dam for two more generators in the future, which will bring the ultimate capacity of the station up to 125,500 kv-a.

The unique feature of the station is the electrical layout. The conventional switchboard has been entirely eliminated, and has been replaced by individual control panels installed in cabinets or "cubicles" alongside of each generator. Each cubicle contains relay mechanisms for controlling its generator, together with protective equipment. These cubicles are constructed of steel, and are provided with glass doors, both front and rear, so that all devices and instruments can be seen without opening the cabinet.

A supervisory equipment makes it possible to assemble the control and metering of all generators on a single panel at the desk of the supervisor. This panel is approximately six feet long by three feet high by one foot deep, and on it are mounted eleven banks of instruments and keys by which the condition of each generator and transformer bank can be determined and controlled by one man.

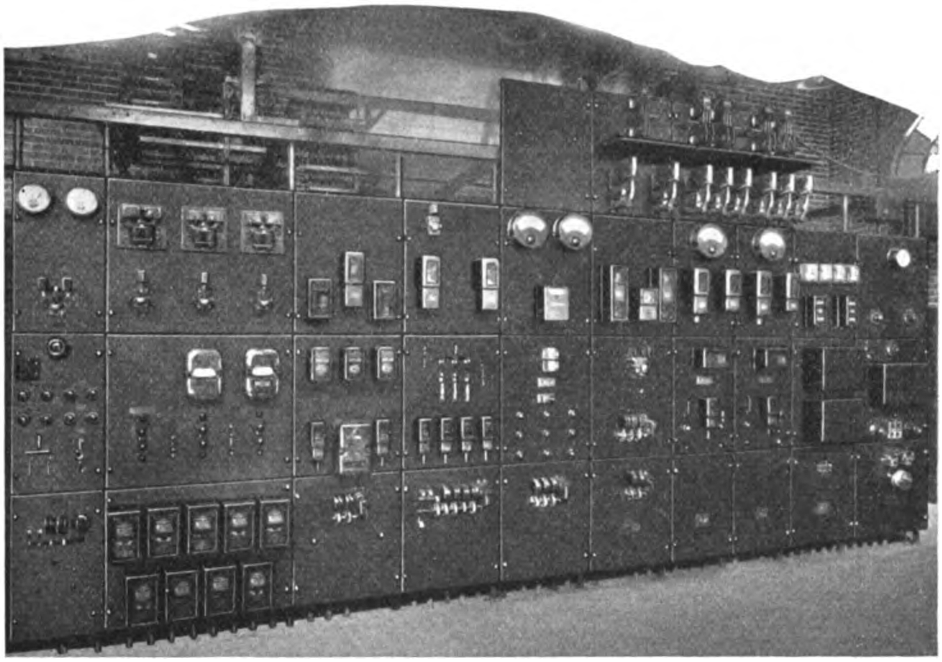

Fig. 98. Automatic Switchboard Controlling Mercury-arc Rectifier in a Station of the Chicago, South Shore & South Bend Railroad

Synchronous Condensers

The Syracuse Lighting Company utilizes a 2500-kv-a. synchronous condenser with complete automatic control. The machine is started by means of a direct-connected induction motor, its speed increasing to a point slightly above synchronism and a resistance inserted in series with the starting motor then causes it to decelerate slowly. The condenser is automatically synchronized with the line as it passes through the synchronous-speed condition. As soon as the breaker closes, connecting the condenser to the line, the starting motor is disconnected. This equipment makes possible a wide variation of voltage control.

Motor-generators

The Bureau of Yards and Docks provided Puget Sound Navy Yard with an automatically-controlled synchronous motor-generator station. The equipment consists of two three-unit motor-generators of 800-kw. capacity at 125 volts direct current connected to furnish power at 125/280 volts over three-wire feeder circuits. The automatic equipment includes counter-e.m.f. regulation and load-balance control.

The primary function of the station is to supply power to ships while in dock for repairs. To facilitate connection to the ship's power system, plugging stations are located at suitable points along the dock. A switch at each one of these points allows a member of the ship's crew to start the automatic station remotely whenever needed.

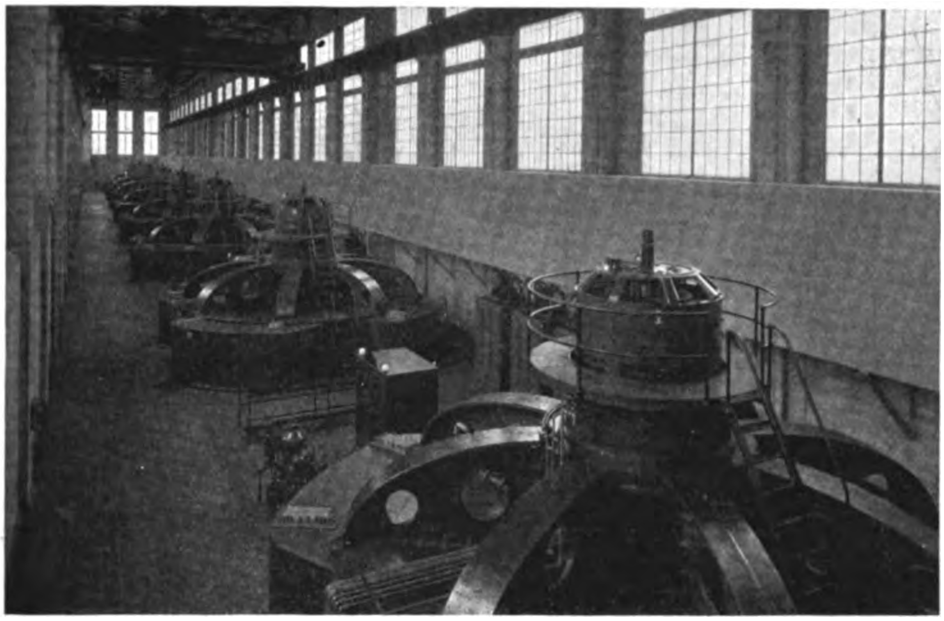

Fig. 99. 100,000-kv-a. Automatic Hydroelectric Station of Louisville Gas & Electric Co.

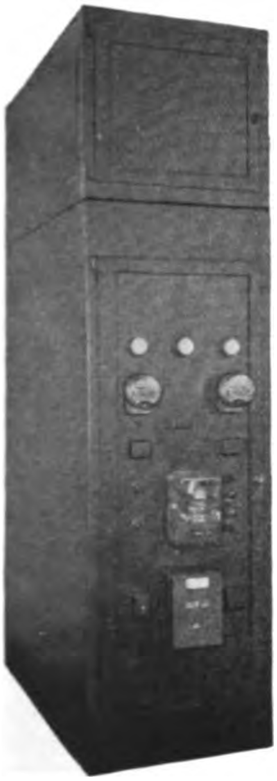

Fig. 100. An Automatic A-c. Reclosing Feeder Cubicle for Equipment of 4000-volt 600-amp. Rating

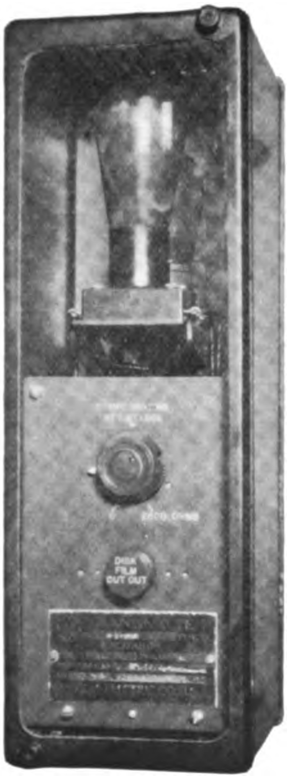

Fig. 101. Rectified-current Transmitter for Automatic Telemetering

Alternating-current Reclosing Feeders

There were no radical changes made in the operating circuits of this type of equipment but there was a general trend toward metal-enclosed self-contained units (Fig. 100) which afford the same accessibility to oil circuit breakers, instruments, etc., as the open type of construction. They are easily installed, occupy a minimum of floor space, and may be placed side by side to form a continuous switchboard. They are particularly adaptable where a dusty atmosphere is present and in cases where safety precautions are especially desirable.

Automatic Telemetering

As a means of simplifying telemetering equipment, a rectified-current type was developed which, when used with the synchronous-selector supervisory system, requires no extra line wires. A transmitter and a receiver may be connected to any one of a large number of substation circuits. The equipment is simple to operate and maintain since there are no moving parts except the indicating or recording instruments at the dispatcher's station.

The transmitter (Fig. 101) consists of: a special transformer for each circuit to be indicated; a full-wave rectifier tube; a transformer to supply filament current to the tube; line-wire-compensating resistance; and a protective device to prevent the possibility of high voltages or damage to equipment in case of an open circuit in the line wires. The receiving instrument is a standard-type direct-current milliammeter.

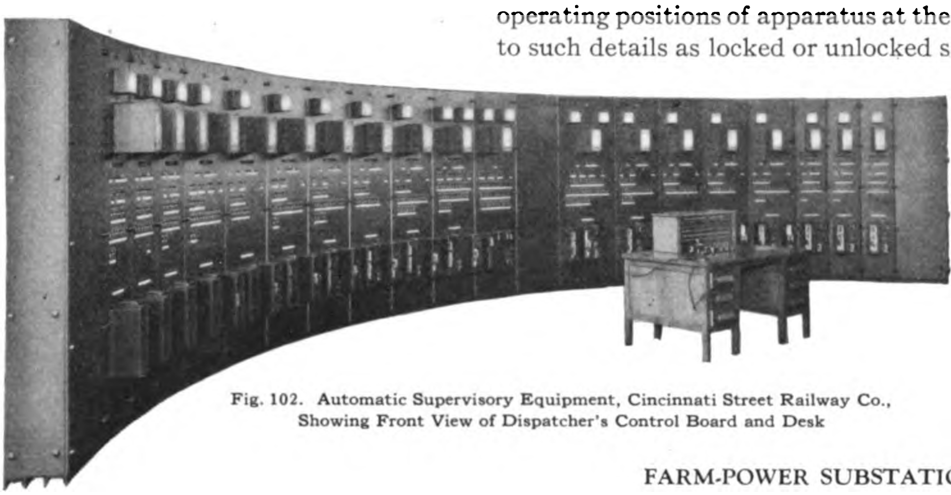

Fig. 102. Automatic Supervisory Equipment, Cincinnati Street Railway Co., Showing Front View of Dispatcher's Control Board and Desk

Supervisory Equipment

The synchronous-selector type of supervisory equipment, which represents one of the latest developments in remote supervision of substations, has simplified to a considerable degree the burden placed on the system load dispatcher. By its use a rapid and accurate means of control and indication is provided at a central point, over four wires. The operation of a controlled unit occurs simultaneously with the pressing of a master key on the dispatcher's board.

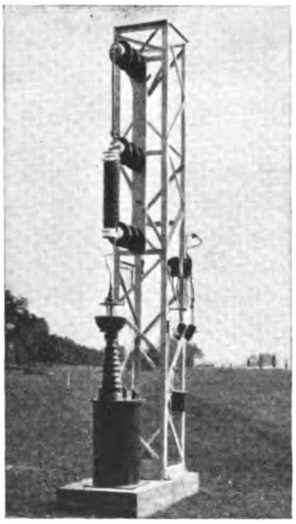

Fig. 103. Farm-power Substation Equipment for Taking Power Direct from High-voltage Lines

An extensive application of the synchronous-selector system has just been made by the Cincinnati Street Railway Company for the supervision of 19 substations located in outlying districts. From this central point (Fig. 102) the dispatcher can start and stop the machines, shift the load from one substation to another, open or close the incoming line breakers, and open or close the direct-current feeders. He also has complete indication, by means of lamps, of the operating positions of apparatus at the substation even to such details as locked or unlocked station doors

FARM-POWER SUBSTATIONS

A small transformer stepdown substation (Fig. 103) was developed to permit power companies to take power safely and economically from high-voltage lines to supply the farm and the small rural community.

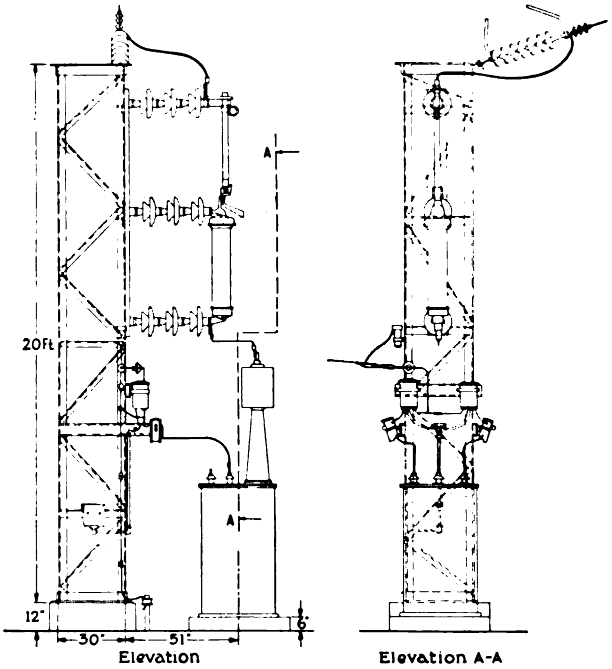

Fig. 104. Structural Arrangement of Outdoor Farm-power Substation Equipment

The cost of reaching and serving scattered rural loads is prohibitive in many cases as long low-voltage distribution lines run into relatively large capital investments that are not justified by the returns secured. To tap high-voltage trunk lines (66,000 or 110,000-volt) has heretofore involved expensive oil circuit breaker and lightning arrester equipment.

The new substation is so designed that a material saving is accomplished by:

(1). Designing the high-voltage insulation throughout so that its resistance to lightning and system voltage breakdown is greater than the resistance of the high-voltage trunk-line insulation itself. The high-voltage line insulation protects the small substation. (2). Substituting for the oil circuit breaker, relays, current transformer, and disconnecting switch, an interrupting and disconnecting device consisting of an expulsion fuse and current-limiting resistor unit, which will protect the high-voltage line against interruption due to faults in the stepdown transformer or substation structure with negligible disturbance to the system.

A number of novel features were incorporated (Fig. 104) to effect economy with an unusual degree of reliability. The transformer employs only one bushing. One end of the transformer winding is solidly grounded inside the tank. The oil in the tank and in the bushing is common, with a conservator mounted on the top of the bushing. Adequate shielding and clearances between the high-voltage and low-voltage windings prevent reflection of over-voltages to the low side by capacity coupling. The core and coils are designed to minimize the possibility of telephone interference. The magnetizing current is practically negligible.

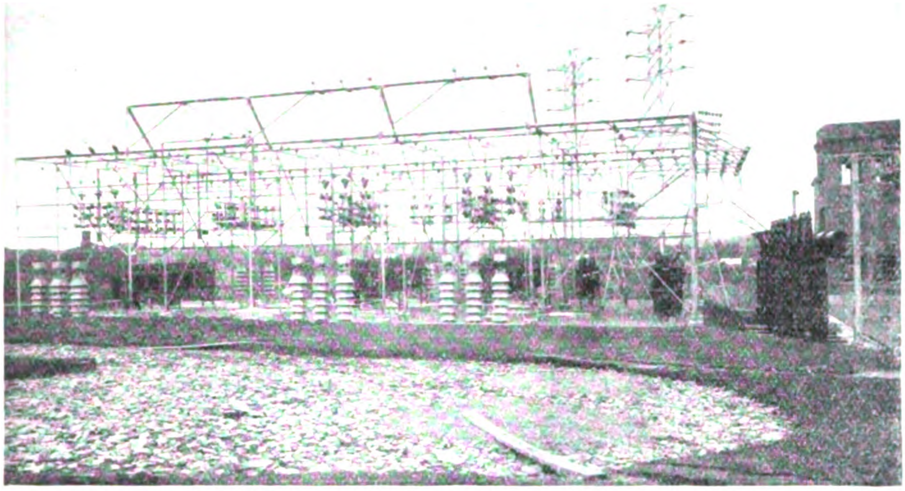

Fig. 105. Typical Modern Outdoor Switching Station with 110-kv. to 33-kv. Transformers

The substation is designed for connection between one conductor of the high-tension line and ground, as the majority of high-voltage lines are operated grounded. The station comprises one high-voltage fuse and resistor, a single-bushing transformer and gives 2300-volt single-phase 60-cycle service. Low-voltage metering equipment, cutouts and arrester are included.

The current-limiting resistor in series with the fuse is employed for the purpose of keeping the short-circuit kilovolt-amperes within the safe interrupting rating of the fuse and preventing a heavy draft of short-circuit current which might operate the line relays, or disturb the system.

On the basis of the high-tension line insulation values usually encountered, the transformer high-tension bushing will have an impulse voltage flash-over value higher than the line, and the high-tension winding of the transformer in turn will have an impulse voltage breakdown value above that of the bushing. Therefore the line insulation will flash over and relieve overvoltages, but if the impulse should reach the transformer terminals the transformer bushing will flash over and protect the winding.

The complete 66,000-volt substation sells for an amount comparable with the cost of building about a mile and a half of distribution line and should give more reliable service and better voltage regulation than the average rural-distribution line.

OUTDOOR STATIONS

The use of outdoor stations for high-tension switching and stepdown transformer equipment is now an accepted practice, and its reduction in cost and elimination of hazard to life and apparatus is rapidly increasing its adoption. Several of the large utilities have already standardized on this practice (Fig. 105) and the demand for heavy-duty low-tension outdoor switching equipment in generator-voltage ratings is rapidly increasing.

To meet the demand for low-tension switching equipment, a heavy-current triple-pole group-operated switch, for both vertical and horizontal mountings, was produced in voltage ratings of 15 and 25 kv. and current ratings of 2000, 3000, and 4000 amp. The design (Fig. 106) is such that switches of higher current ratings can be provided if required.

The design of this switch shows a radical departure from that of the conventional disconnecting switch in that it gives high-pressure contact at both hinge and contact ends of the switch. The blade is hinged on a non-corrodable pin at the hinge end and is entirely free from contacts when opening and closing, thereby insuring easy operation of heavy-current switches.

The blade of each unit consists of two parallel sections of hard-drawn copper, spaced sufficiently far apart that a system of wedges can be inserted between them at both the hinge and contact ends. These wedges are actuated by a combination of linkages which come into action after the blade is in the full-closed position. These wedges serve to establish a high pressure between the blades and the accurately-machined line surface on the contact blocks. A positive pressure in excess of 1000 lb. is established between the blade and the contact and this provides a most efficient path for the current with exceptionally low temperature rise.

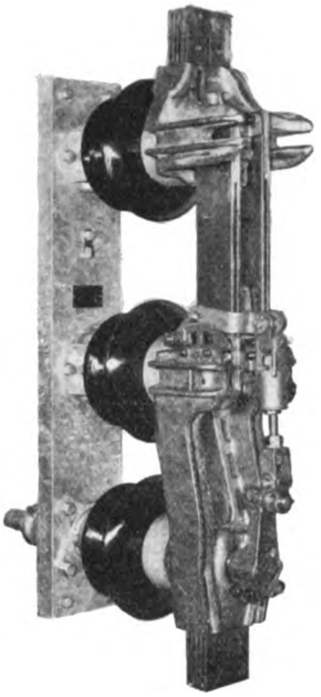

Fig. 106. Heavy-current Disconnecting Switch with High-pressure Contacts

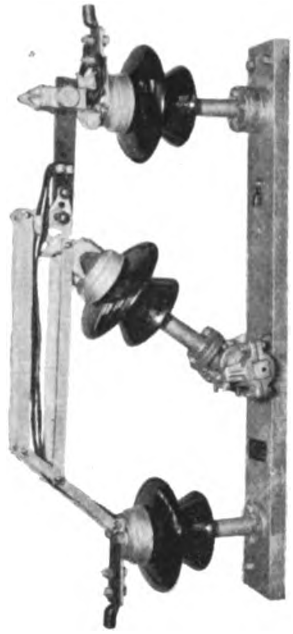

Fig. 107. Disconnecting Switch Rated 400 Amp. at 73 Kv.

In the opening operation of the switch, the first movement of the operating handle releases the pressure at the contacts and the switch then opens freely. This use of high-pressure contacts for heavy currents represents a distinct advancement over previous practice.

For lower current ratings, a triple-pole group-operated switch (Fig. 107) is used on 400, 600, 800, and 1200-amp. circuits in all voltage ratings up to and including 73 kv. This is a tilting insulator type of switch with a full-floating self-aligning spring-pressure type of line contacts.

A new hook-operated switch of 600 and 1200 amp. (Fig. 108) is provided with positive-blade latches and designed to withstand the magnetic stresses encountered at time of short-circuit.

To permit the fusing of potential transformers on large systems, current-limiting resistors were developed which, when used in series with the potential fuse, permit their application to any system regardless of the possible short-circuit current of the system.

A combined expulsion fusible cutout and disconnecting switch (Fig. 109) was developed to meet the demands for a high-interrupting-capacity fuse which was positive in operation. It has been produced in ratings of from 7500 volts to 73 kv. and in current ratings up to 100 amp. with interrupting capacity of 100,000 kv-a. Positive operation is assured by the introduction of a spring which is held in compression until the link fuses and then assists the expulsion action in removing the conducting parts from the tube, thus assuring a positive interruption of the arc. This fuse is factory filled, which assures correct fusing and eliminates faulty application of fuses by the operator.

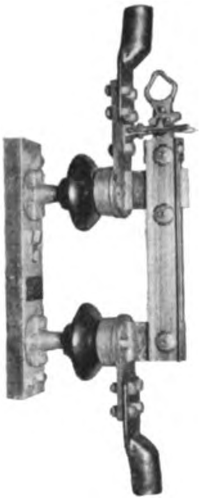

Fig. 108. Improved Type of Hook-operated Disconnecting Switch Rated 1200 Amp. at 7500 Volts

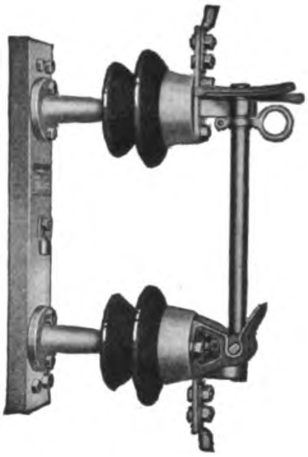

Fig. 109. Combined Fuse and Disconnecting Switch in Closed Position

The use of group-operated switches for high-tension equipment has now become an accepted practice and for the horn-gap type of switch the vertical-break form is being increasingly used. For this service, a tilting insulator type (Fig. 110) was produced for voltages of 88 and 110 kv. and a rotating insulator type (Fig. 111) for voltages up to 220 kv.

In all these high-tension switches, the line pressure contacts are used with corrosion-resisting materials for springs, pins, etc.

Outdoor Switch Houses

The design of outdoor switch houses was modified so as to provide greater access to the equipment. In the small-size house, rated at 4500 volts, the relay and instrument panel has been placed above the oil circuit breaker and its mechanism. However, the height of the arrangement has been so fixed that all devices are within the reach of the average person. The small-type house (Fig. 112) is especially adapted to industrial use where space for such apparatus may be limited.

In the larger types rated at 15,000 volts (Fig. 113), the panel has been placed alongside of the oil circuit breaker and its mechanism, making all the apparatus more accessible and decreasing the height of the structure.

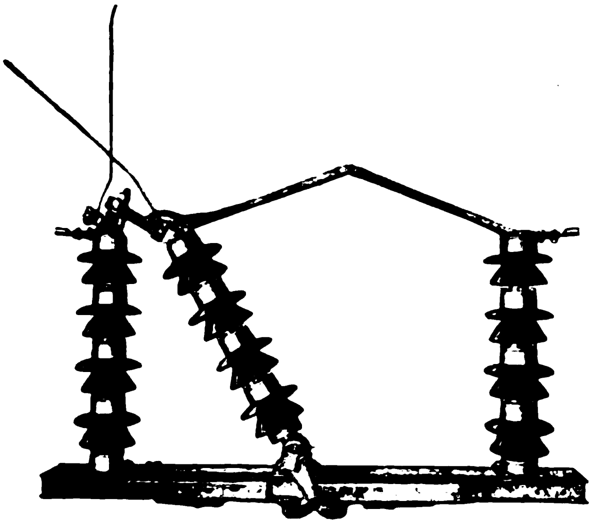

Fig. 110. Horn-gap Tilting Insulator Type of Switch for 600-amp. 110-kv. Circuit Provided with Enclosed Counterbalancing Springs

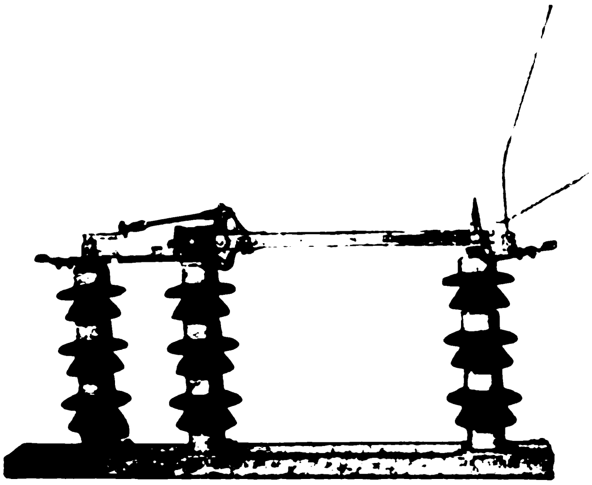

Fig. 111. Rotating Insulator Type of Horn-gap Switch for Circuits up to 220 kv.

SWITCHGEAR

Metal-clad

A distinct departure from conventional designs was made in the equipment for the 33-kv. outdoor switching stations recently placed in service at Wheaton (Ill.) by the Public Service Company of Northern Illinois. All live parts, including the buses and connections, are completely surrounded by metal which arrangement accomplishes the twofold purpose of preventing casual contact with the live circuit and of limiting any possible fault to a phase to ground failure which cannot possibly communicate to other phases or circuits. All operations are interlocked mechanically or electrically or both.

Energy is delivered to the station by overhead lines connected with underground cable leading to the metal-clad switchgear station. Both the main and reserve buses of this station, together with all of their control and auxiliary apparatus, are mounted on a massive steel structure outdoors. Operation is controlled from an adjacent substation building.

Provision is made for seven circuits (Fig. 114) which can be fed from either the main or reserve bus

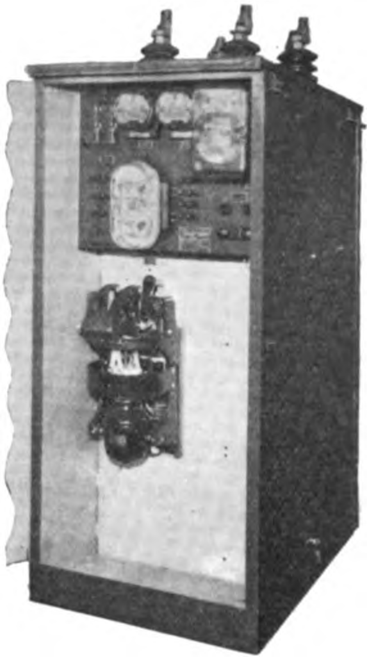

Fig. 112. 50-amp. 2300-volt Alternating-current Reclosing Feeder in Outdoor Switch House

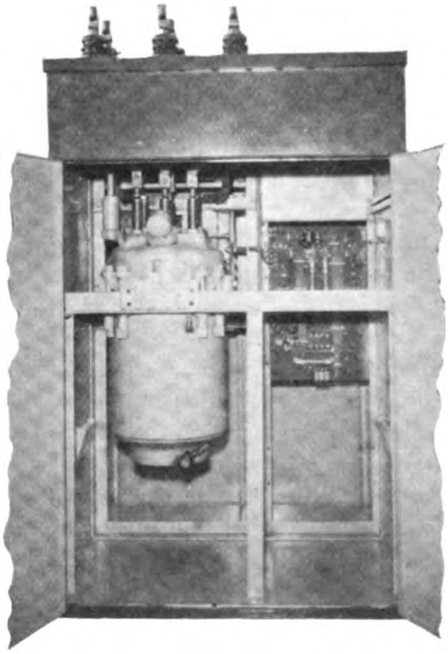

Fig. 113. Outdoor Switch House for 800 and 1200-amp., 7500 and 15,000-volt Circuits

and each bus has an auxiliary transformer. Each circuit occupies a separate bay in the steel structure and an additional bay, totally enclosed, is provided for use as a storage house and repair shop.

The buses are housed in grounded metal pipes connected through expansion joints to suitable junction buses. The conductors themselves are copper tubes with wrapped-on insulation supported in the tubes by spools located at regular intervals. Free circulation of the oil through the tubes is provided for and barriers prevent the disturbance of the oil level in any one section by a leak in any adjacent section. Oil conservator tanks are used.

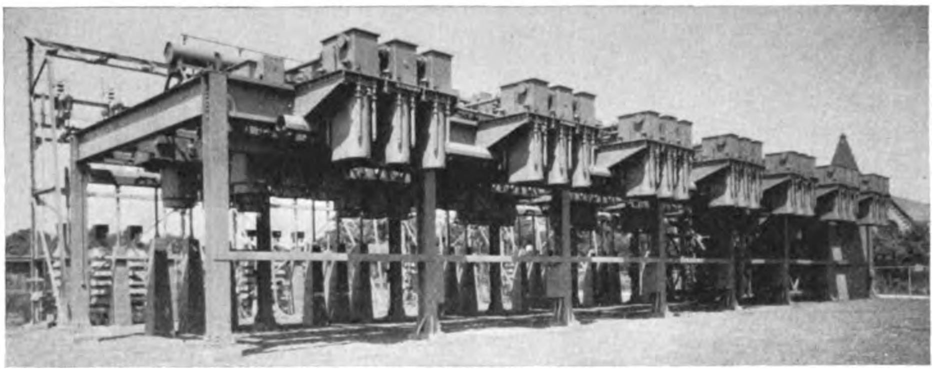

Fig. 114. Metal-clad Switching Equipment at the Wheaton Substation of the Public Service Corporation of Northern Illinois

The insulation and clearances are such that the equipment can operate for a short time at normal voltage even though all of the oil had leaked out.

An outstanding feature of this installation is the elimination of disconnecting switches. The oil circuit breakers are disconnected from their circuits (Fig. 115) by lowering them bodily with a traveling motor-operated elevator. The breaker may be dropped to a support at the disconnected position where its mechanism may be tested or its tanks lowered or the breaker rolled into the repair house at the end of the structure if desired and a spare breaker may be immediately substituted. As the circuit-breaker bushings leave the enclosing shells which support the stationary contacts, the openings are automatically closed by shutters. When the breaker is replaced it is held in its connected position by six cams mounted on the girders of the breaker housing and operated through a worm-and-gear mechanism powerful enough to lift the entire breaker.

The mechanical interlocks preclude any possibility of false operation, such as releasing the clamping device when the elevator is not in its proper position, or removing or replacing a breaker when its contacts are closed, or operating the clamping device when the breaker is not in the connected position. It is also impossible to remove the tanks if the breaker is not in the disconnected position.

The breakers are rated to interrupt 1,000,000 kv-a. at 37 kv. and are made up of single-pole units bolted together with the motor-operating mechanism mounted on one end. Explosion-chamber contact construction is employed.

The connections are such that any section of bus can be removed without disturbing the other sections. Through-type current transformers are used. The potential transformers are equipped with housing and disconnecting contacts similar to those provided for the oil circuit breakers. These latter transformers are also provided with a separate traveling elevator.

Power for the operation of the oil circuit breaker elevators is obtained from connection boxes in each bay. Each of these circuits is so interlocked that power is not available for operation of the elevator when the oil circuit breaker is in place and in the closed position.

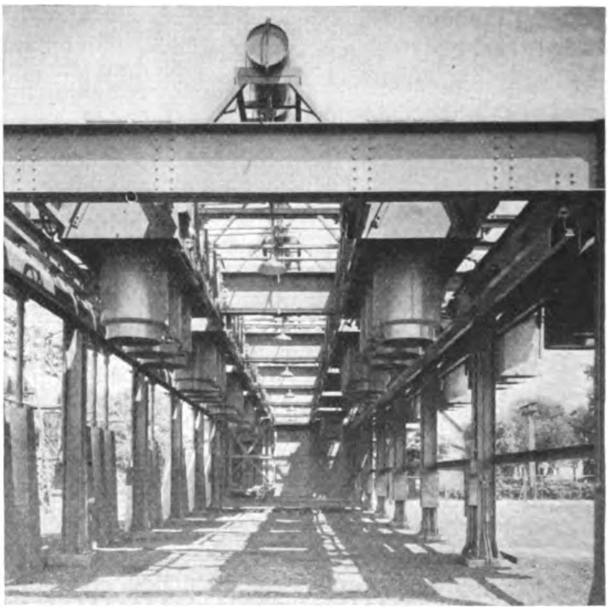

Fig. 115. Arrangement of Circuit Breakers at the Wheaton Substation

The total enclosure of every current-carrying part not only gives protection to operators and maintenance men but prevents secondary breakdowns which may occur in open-type switching equipment.

Oil Circuit Breakers

A new oil circuit breaker, to provide moderately high interrupting capacity, was made up of separate single-pole units each of which occupies but a minimum amount of space.

It will be built in sizes ranging from 600 to 2000 amp. at 15,000 volts and with interrupting capacities of 125,000 to 350,000 kv-a. at rated voltage. It is especially adaptable to removable-truck mounting but can also be applied to framework or cell mountings.

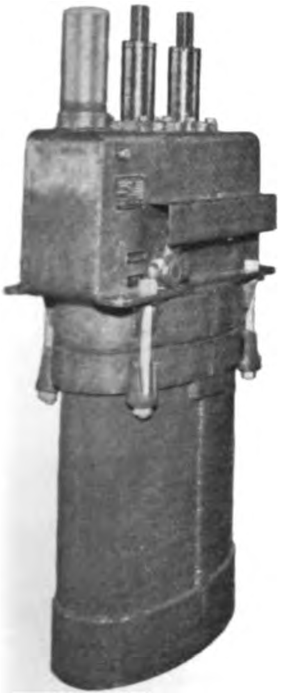

Fig. 116. 1200-amp. 15,000-volt Single-pole Single-throw Elliptical-tank Oil Circuit Breaker

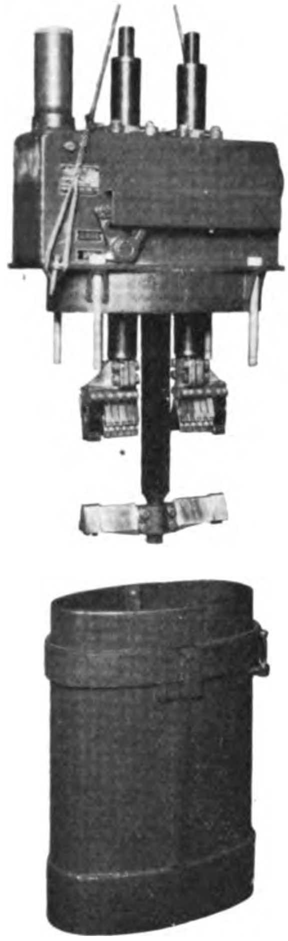

Fig. 117. Internal Arrangement of Single-pole Single-throw Oil Circuit Breaker, Shown with Elliptical Tank Removed

The elliptical tanks (Fig. 116) used for this breaker are thoroughly reënforced at top, bottom and sides. No castings are used, the entire tank and cover being of welded steel-plate construction. Each tank and cover is pressure-tested far beyond its service requirements.

Other features of construction heretofore characteristic of only the highest capacity breakers are included. Among these are the short-bolt principle of tank suspension (Fig. 117), the use of a breaker mechanism which is entirely "internal" to eliminate possible reclosure during or after circuit interruption, and the use of wide-angle finger and wedge contacts identical with those used on many of the larger breakers. Herkolite bushings, rigidly braced, provide insulation and resistance to momentary magnetic stresses set up by the transient short-circuit currents which this breaker will be called upon to interrupt.

A new oil circuit breaker for outdoor service at 4500 volts (Fig. 118), with provision for framework or for switch-house mounting, was designed for distribution service where the interrupting capacity demands are moderate. With normal current ratings of 400 or 600 amp., it has interrupting ratings of 3200 amp. at its rated voltage or a maximum of 20,000 amp. at 600 volts.

Either manual or electrical operation may be used. Manual operation may be obtained either directly at the breaker or at the base of the pole on which it is mounted. A built-in tripping device may be used for instantaneous or time-delay operation, energized directly from bushing-type current transformers. The tripping mechanism is so designed that the breaker is at all times trip-free from the manual operating handle. Electrical operation is possible by means of a standard motor mechanism.

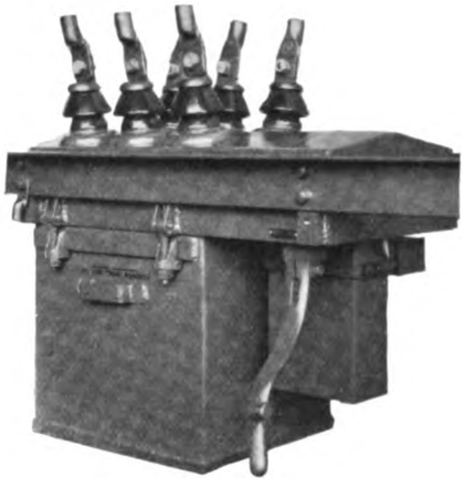

Fig. 118. New Type of Triple-pole Single-throw Oil Circuit Breaker for Outdoor Service at 4500 Volts

All three phases are enclosed in the same sheet-steel tank secured to the frame by cleats, and one-piece porcelain bushings are used to insulate the conducting studs which terminate in finger contacts. The bushings have a dry flash-over of 43 kv. minimum and the entire breaker is equally insulated. The breaker is weatherproof in every respect.

Metal Switchboards

In line with the use of steel for mounting switchboard devices on metal-enclosed equipment, steel panels are also being used in open types of construction where slate or other material was formerly employed. Of one-piece construction (Fig. 119), the lining up of individual panels for a continuous switchboard becomes a very simple matter. The danger of breakage of panel material is eliminated and a lighter-weight structure is secured.

A further refinement consists of painting the main circuit connections on the panel, a variation in colors being employed to distinguish between different types of circuits.

Motor-generator Control

With the increasing demand for electrically-operated shovels, a new application was found for metal-enclosed switching equipment. This consists of a switching unit of cubicle construction (Fig. 120) housing the control for the motor-generator which provides the power supply for the shovel. In order to withstand the severe service to which shovel equipment is subjected, a rigidly constructed and self-supporting design was adopted.

In the restricted space available, the protection afforded the personnel by this type of enclosure is well worth consideration. With modifications to the apparatus, this unit can be readily applied to motor starting equipment for pumps, compressors, etc.

The steel cubicle (Fig. 121) was adapted as part of a switchboard for the pull-button control of motor-generators. All the control devices and instruments for the motor are mounted on a hinged door or panel, and the breakers with their mechanisms for starting and running are located inside the cubicle. The direct-current switchgear is mounted on an adjacent standard panel.

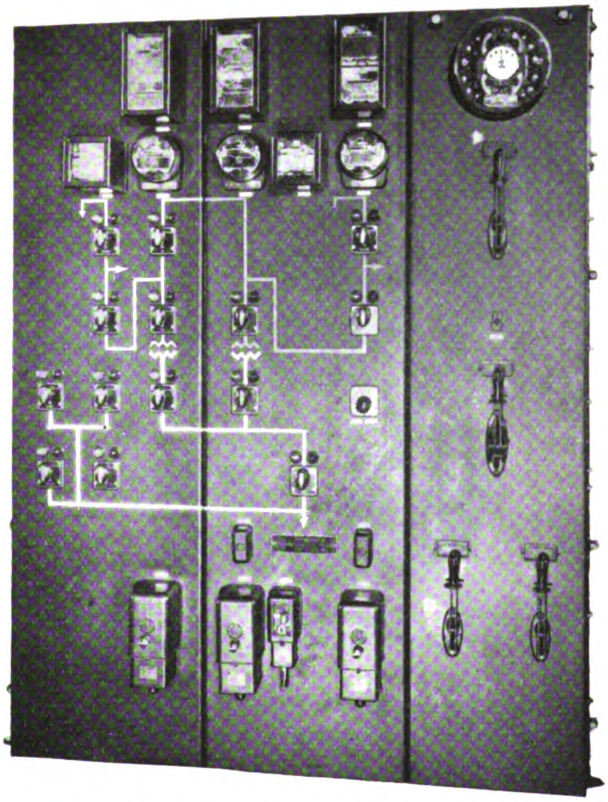

Fig. 119. Typical Switchboard Made up of Steel Panels, Showing Painted Indication of Main Circuit Connections

Relays

A differential-current relay for the protection of three-winding power transformers operates on the principle of current restraint.

It has two disks (Fig. 122) on a common shaft actuated by three restraining elements and one operating element. The three restraining elements are connected to three current transformers in the power transformer circuit. The current transformers are so connected that under normal operating conditions the resultant current is zero; but when a fault occurs the equality no longer exists and current flows through the operating coil of the relay which forms part of the common return to the current transformers. When this current rises to 25 per cent of the main-current value, the relay functions.

An induction relay for the protection of load-ratio control units (Fig. 123) has three single-phase units in one case, each unit having one restraining and one operating element. The restraining coils are connected to the main current transformer while the operating coils are connected in the exciting windings of the load-ratio control unit. Under normal conditions of 10 per cent buck or boost, the exciting winding takes a current equal to that of the main power transformers. When the current (because of a fault) reaches a value of 2½ times the main current, the relay will function.

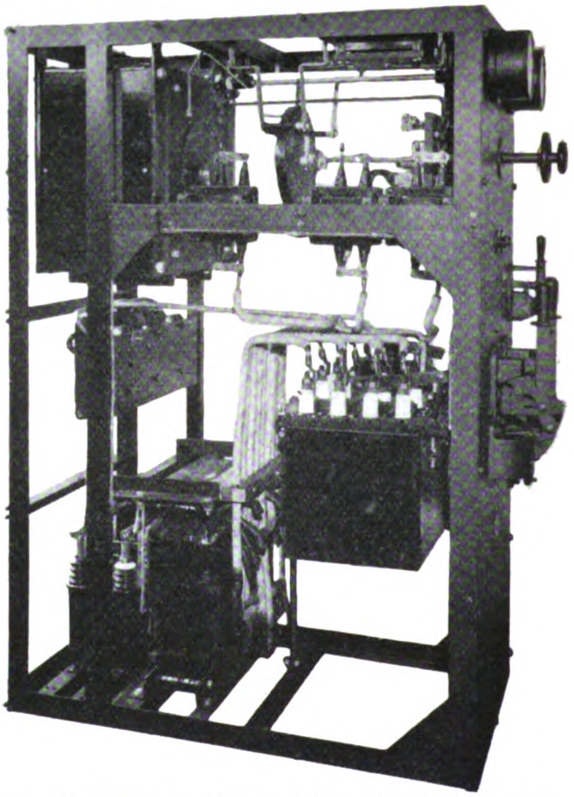

Fig. 120. Safety-enclosed Type Panel Developed for Control of Electric-shovel Equipment, with Sides Removed to Show Construction

Instantaneous induction overcurrent relays were developed for use primarily with the carrier-current pilot protective system. The overcurrent "starting" relay (Fig. 124) and the "tripping" relay are similar in construction, with an aluminum disk actuated by high-torque driving magnet to obtain practically instantaneous operation and short disk travel to close contacts.

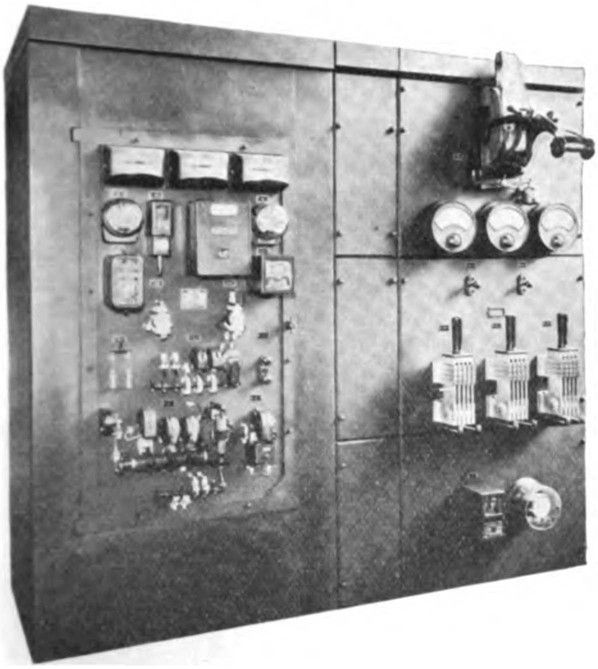

Fig. 121. Arrangement of Automatic Switching Equipment for 1000-kw. Motor-generator Set

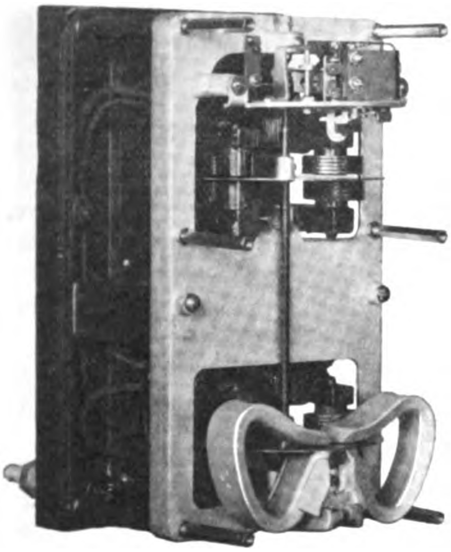

Fig. 122. Differential-current Relay for the Protection of Three-winding Power Transformers

The "tripping" relay has in addition a holding coil and target mechanism, and also a locking coil to hold the trip contacts open against overcurrent until a receiver relay, actuated by carrier-controlled current, opens its contacts and releases the locking action. By using such relays in the carrier-current pilot protective system, the circuit-breaker trip circuit is energized 0.25 sec. or less after a fault occurs in the protected section of the transmission line.

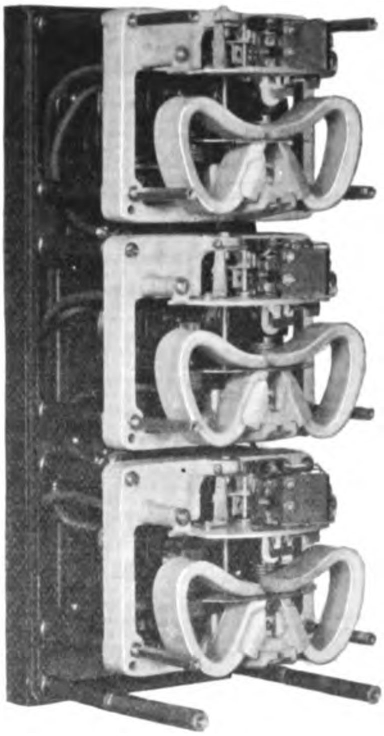

Fig. 123. Induction Differential Relay for the Protection of Load-ratio Control Units

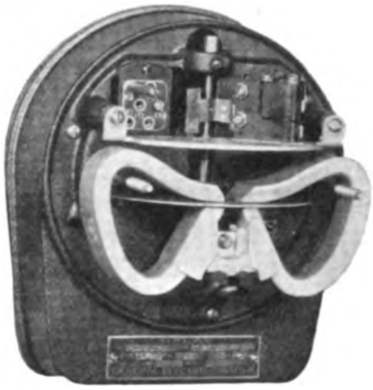

Fig. 124. Instantaneous Induction Overcurrent Relay for the Carrier-current Pilot Protective System

An auxiliary relay was designed to control the potential circuits of reactive kilovolt-ampere meters in cases in which it is desired to measure incoming and outgoing lagging or leading kilovolt-amperes. It is also suitable for use in cases in which a double-pole double-throw relay with non-arcing contacts is required. The relay is essentially an electrically-operated switch (Fig. 125) having two single-pole double-throw mercury contacts and two operating coils suitable for momentary use on either a 110-volt alternating-current or direct-current circuit. By using one of the mercury contacts in combination with the operating coils, the relay may be controlled by a simple snap switch with one control wire.

An electrically-operated timing device (Fig. 126) supplements the oil dash pot used in connection with the control valve of an oil-operated waterwheel governor. It consists of a small motor driving, through a train of gears, a pinion which extends from the case of the device to engage a rack attached to the stem of the control valve of the governor. It functions to restrain the operation of the governor control valve by allowing it to open only at a uniform speed. In this manner, the acceleration of the waterwheel is maintained at a constant rate regardless of the temperature, which affects the viscosity of the oil in the oil-dashpot type of control and therefore the acceleration. The device is arranged to stop the motor of the waterwheel gate at the running-light position and to allow it to open further as soon as the machine has been synchronized and connected to the line. It again stops the gate motor at full-gate position.

A network relay which requires a high reverse current to trip at normal voltage and yet which is very sensitive at short-circuit voltage was produced. It consists (Fig. 127) of a wattmeter element plus another coil which is wound on the same iron structure as the current coils and excited by the same voltage that energizes the potential coil. The current coils are energized by current transformers. When the direction of power is reversed, the flux due to the current bucks that due to the restraint until at a certain predetermined value it overcomes that restraint and closes the relay contacts, thereby tripping the network protector. The relay may also be used to reclose the protector also by not making use of the restraining circuit when the protector is open. The restraining circuit is opened by an auxiliary switch.

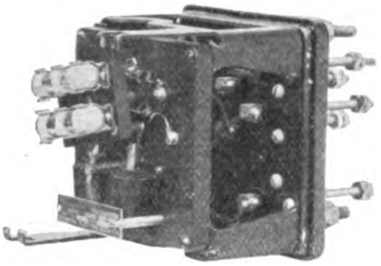
Fig. 125. Auxiliary Relay to Control the Potential Circuits of Reactive Kilovolt-ampere Meters

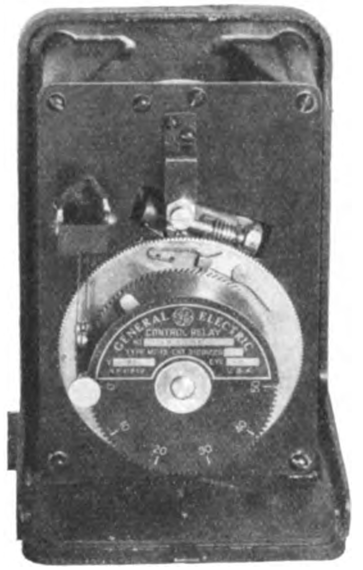

Fig. 126. Timing Relay for the Control of Waterwheel Governor

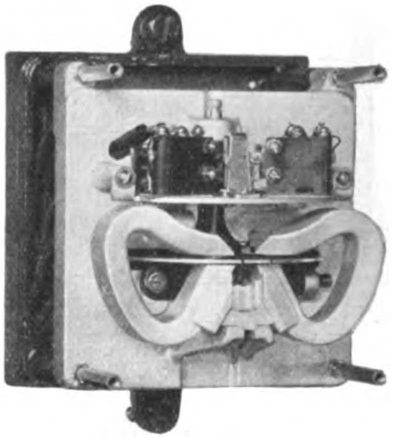
Fig. 127. Network Relay for High Reverse Current Trip

For the protection of low-voltage alternating-current networks, the feeder transformers of which are connected delta on the low-voltage side with the middle tap of one winding brought out to obtain lighting voltage, three new network relays, a power directional, an overcurrent, and an overvoltage relay were developed. The three relays are used as a relay combination which is not sensitive to small reversals of power, but which trips quickly on transformer or feeder faults. The network protector will remain open until the overvoltage relay, which can be set for any predetermined value, operates to close it.

METERS

Two new types of alternating-current watthour meters were developed.

One of these (Fig. 128) is a two-element three-wire meter intended for metering that class of three-wire service obtained from two phases of a four-wire three-phase circuit in low-voltage network systems. The new single-phase meter improvements referred to in last year's review were extended to this two-element meter, giving it the same excellent performance characteristics. Several distinctly new features were incorporated, including the method of attaching and sealing the glass cover and a micrometer adjustment for equalizing the torque of the two elements.

The other meter (Fig. 129) still further extends the application of the new single-phase meter element. It is intended for polyphase service and has terminal connections at the bottom in a separately-sealed chamber, and micrometer adjustments for power-factor and for balance of the elements. It is also accurately compensated for temperature variation at all loads and power-factors.

Modern operating conditions in central stations require that the accuracy of frequency meters be of an unusually high order under normal conditions and have no appreciable voltage, wave-form, or temperature errors when operated under extreme conditions. A new line of frequency meters was developed to fulfill these requirements.

The instrument (Fig. 130) is of the improved resonant-circuit type in which the deflecting torque is proportional to the difference in the squares of the currents of two resonant circuits. This improved circuit makes it possible to obtain an unusually wide deflection of the pointer per cycle change in the circuit.

The inherent advantages in the horizontal-edgewise line of instruments are retained: the anti-parallax scale in which the pointer-target is flush with the scale face (this permits extremely close readings regardless of the angle from which readings are taken); and the vertical-shaft construction which minimizes bearing friction. The latter feature is responsible for the sustained accuracy of horizontal-edgewise instruments.

These instruments are supplied only with 110-volt windings (100-125 volts normal); transformers being required for higher voltages. The line includes five scale calibrations, the most sensitive having a full-scale range between 59.5 and 60.5 cycles. Other calibrations are for 2, 5, and 10 cycles, arranged for service on 25, 50 and 60-cycle systems.

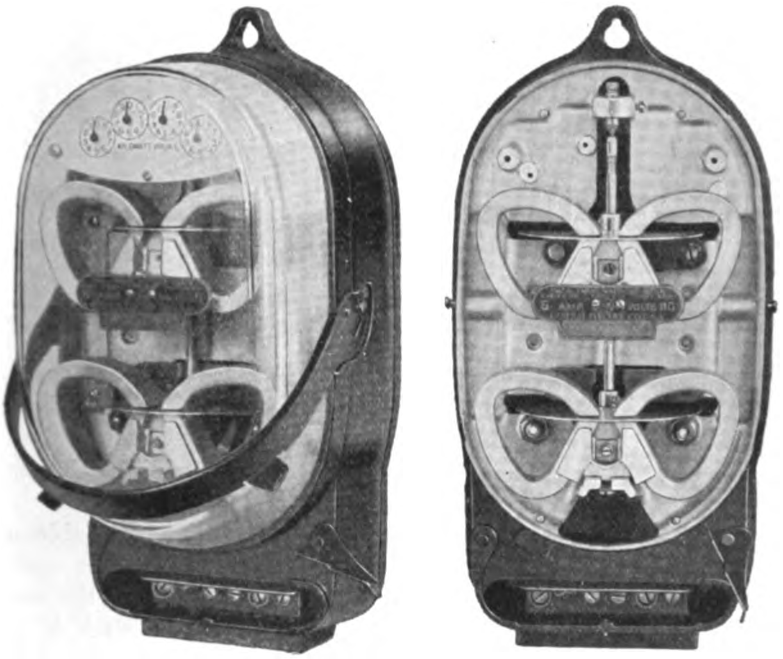

Fig. 128. Improved Watthour Meter, Showing at Left Latch Open and Lock Lever Raised, and at Right Cover and Register Removed

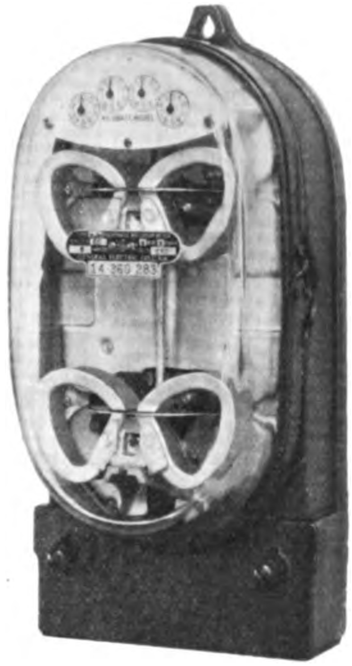

Fig. 129. Improved Polyphase Watthour Meter Compensated for Temperature Variations at All Loads and Power-factors

A new line of strip-chart recording instruments (Fig. 131) was designed for general-purpose recording.

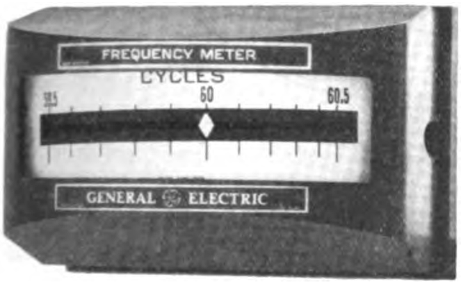

Fig. 130. Frequency Meter of Improved Resonant-circuit Type

The alternating-current instruments embody high-grade "dynamometer" elements, while the direct-current instruments are of the permanent-magnet type. All are properly jeweled and are so constructed that friction is negligible. The pen which produces the record is directly connected to the armature of the instrument, and records, without delay, fluctuations in the circuit to which it is connected.

The case is of steel, 5½ in. wide so that four instruments can be mounted side by side on a panel 24 in. in width. The chart record space is 4 in. wide, the damping is magnetic, and the pen comes to rest in one second with no "overshoot."

LIGHTING

A preliminary estimate of the number of incandescent lamps sold in the United States during 1928 (Fig. 132) indicates 319 million large and 240 million miniature lamps. The former is an increase of about 1½ million (about a half of one per cent) and the latter an increase of about 20½ million (about 9½ per cent) over the previous year. These sales are the largest in the history of the industry.

The present standard line of lamps with inside frosted finish, which was introduced a little over two years ago, made excellent progress in replacing the corresponding old types of lamps in the straight-side clear bulbs. The demand for the new lamps is now about 98 per cent of the total demand for standard wattages. The remaining demand of 2 per cent for the old type lamps comes from special services where clear-bulb lamps are required.

The price trend for lamps has been downward for the past seven years and current prices for both large and miniature lamps (Fig. 133) show marked reductions as compared with those of 1914. At the close of the year, large lamp prices were 49.2 per cent and those for miniature lamps were 48 per cent of the corresponding 1914 figures.

A notable development was the introduction of the inside-colored lamp to supersede the outside-coated or sprayed-finish type previously used. While bulbs of natural-colored glass have been used to some extent, their relatively high price has limited their application.

The outside-coated colored lamps were not entirely weather-proof, the colors tending to fade from exposure to the elements. The new process sprays a coating on the inside of the bulb so that the color is permanent, not being affected by the weather; and the lamp, having a smooth outside finish, can more readily be cleaned.

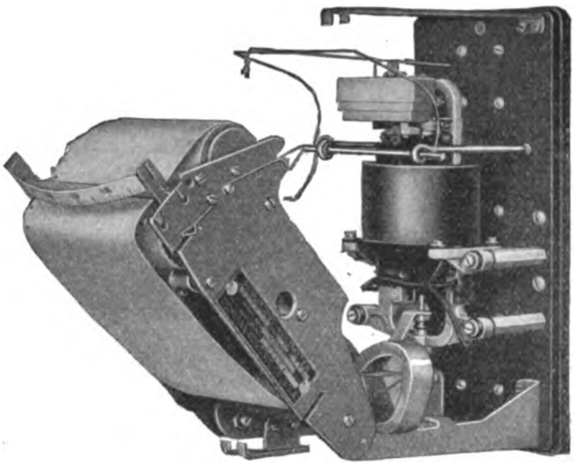

Fig. 131. Strip-chart Recording Instrument for General-purpose Recording

A 56-watt street railway lamp with inside-frosted bulb, for use five in series on 525 to 650-volt circuits, was produced. This lamp has a special filament designed to withstand vibration on street cars and will supersede the corresponding size in the straight-side clear bulb.

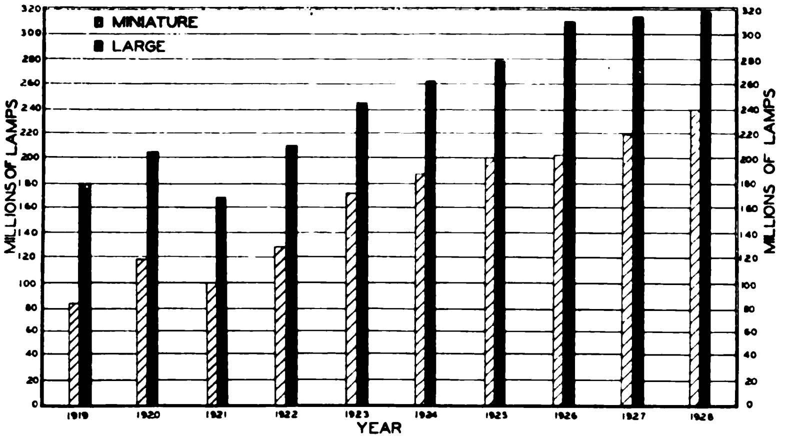

Fig. 132. Number of Incandescent Lamps Sold in the United States, 1919–1928 (1928 estimated)

Two other inside-frosted street-railway lamps were standardized. They are rated at 30 volts 1 amp. and 30 volts 1.6 amp., and are designed for operation approximately twenty in series on street railway circuits. They are made with a special construction which short-circuits the lead wire when the lamp fails, thereby preventing a destructive arc from traveling up into the socket and also maintaining the circuit through the remaining lamps in the series.

These lamps have a marked advantage over the 115-volt lamps operated five in series as they are of gas-filled construction and are from 30 to 40 per cent more efficient. Also they maintain their candle power better throughout their life. This system of lighting has the further advantage that the failure of one lamp does not extinguish the remaining lamps in the circuit and the burned-out lamp can therefore be readily located.

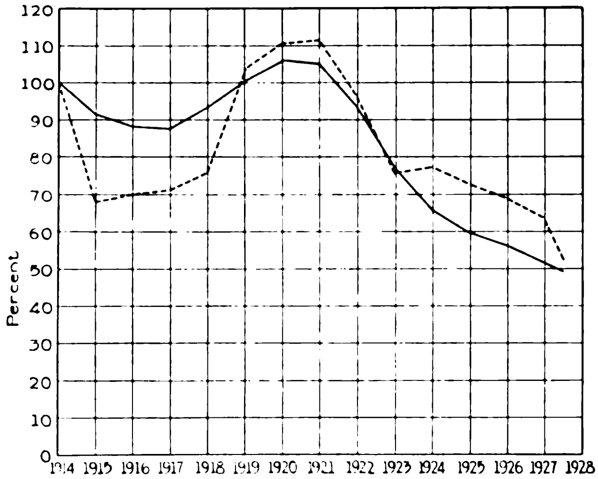

Fig. 133. Reductions in Prices of Mazda Lamps Since 1914

Large Lamps ———— Miniature Lamps.............

A 50-watt 115-volt lamp is now available for projection service where similar results could formerly be obtained only by the use of low-voltage lamps. Other sizes of projection lamps with the coiled-coil filament, now standard, are the 100 and 200-watt 115-volt lamps in tubular bulbs.

In the smaller sizes of street series lamps, a new construction was devised to eliminate certain trouble experienced by an arc being carried up into the socket when the lamp fails. The lead wires above the filament are now brought close together so that if an arc is maintained and continues up the lead wires, it short circuits them thereby stopping the arcing and maintaining the circuit.

For the 4000-lumen 15-amp. and the 6000 and 10,000-lumen 20-amp lamps the bulb sizes were reduced, making the light-center lengths the same as for the 4000 and 6000-lumen 6.6-amp. lamps. This change simplifies fixture design because of the standardization of one light-center length on the higher candlepower lamps and has also effected economies in manufacture with resultant reductions in price.

A new, small, tubular lamp rated at 25 watts, 110, 115, 120 volts, intermediate screw base, is $\frac{11}{16}$ in.

in diameter and 5½ in. in overall length. The diameter of the lamp is about the same as that of the intermediate socket; hence this lamp is especially useful where space limitations prevail. It makes possible the design of extremely neat and compact showcase lighting equipment and has also been found effective for illuminating displays, models, etc., from beneath and for light ornaments of such proportions as to require a small extended light source.

Steady improvement was secured in lamps for aviation lighting, and a 10-kw. unit (Fig. 134) was standardized for this service with a rectangular-shaped filament 70 millimeters wide by 30 millimeters high. This construction assists in spreading a fan-shaped beam of light over the landing field.

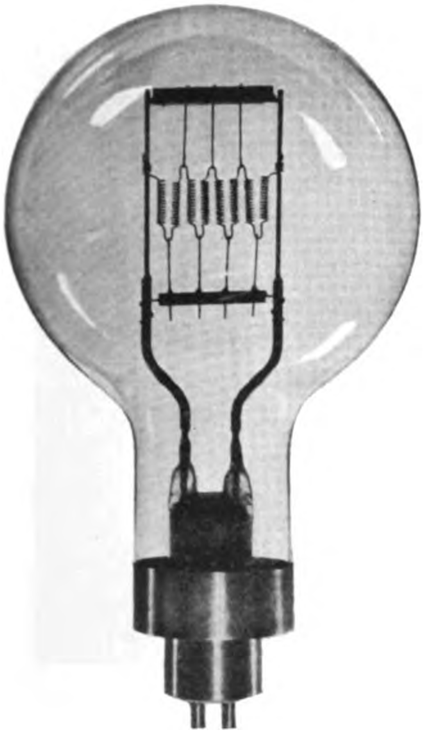

Fig. 134. 10-kw. Lamp for Aviation Field Lighting

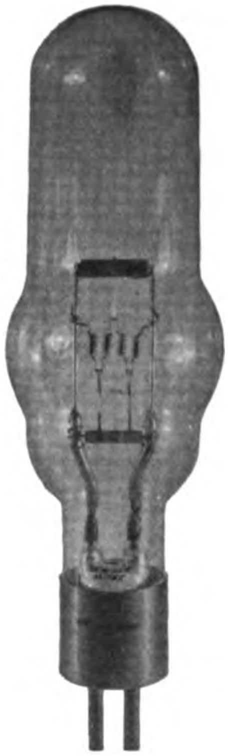

Fig. 135. 3-kw. Lamp for Multiple-lamp Field Lighting Projector

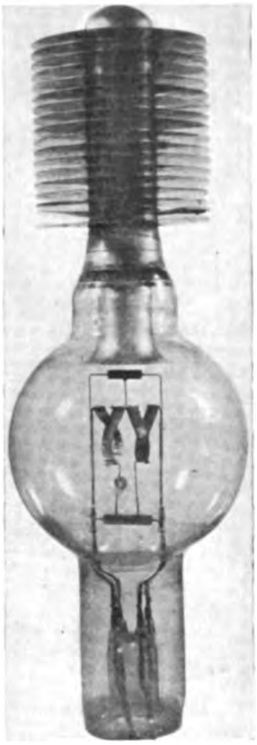

Fig. 136. 50-kw. Lamp Provided with Fin-type Radiator

A 32-volt 3-kw. lamp (Fig. 135) was also used extensively for field lighting.

The most powerful incandescent lamp so far constructed (Fig. 136) is rated 50 kw. and is so designed that the heated gases rise from the filament and are passed through a channel equipped with a radiator to cool them to a temperature which will permit the continued operation of the lamp. This lamp will also be utilized for aviation field lighting.

The introduction of sound pictures necessitated the development of small lamps having high efficiency and horizontal coil-type filaments for projecting the sound record on the film through a very small slit and onto the photo-electric tube. Flattened leads (Fig. 137) are used to allow for the expansion and contraction of the filament and to keep it from bowing.

A new type of lighting unit to enable the amateur to take motion pictures indoors uses a 500-watt lamp burned over voltage to an extent which reduces its life to about 5 hours. This, however, is justified because by doing so a very great increase in the actinic value of the light is obtained.

The success of the medium prefocused base lamp and socket for use in projection equipment led to the production of a mogul size (Fig. 138) prefocused socket and base. It can be utilized on any lamps regularly supplied with a mogul screw base. The additional cost will usually be more than offset by the elimination of focusing adjustments, and the better average illumination results assured.

The International Commission on Illumination met for the first time in America, at Upper Saranac (N.Y.). The meeting was expanded into the first International Illumination Congress which made a tour of inspection of American cities and lighting institutions, and attended the annual convention of the Illuminating Engineering Society. The presentation included a wide range of live topics, in 56 papers and reports.

A new movement for coöperation between the lighting industry and the architectural profession was started, to insure more adequate wiring of buildings, and to meet the growing requirements for illumination. The attitude evinced by the American Institute of Architects indicates a closer working together of these two groups in the future.

Variations in the density of opalescent glassware cause considerable variation in the light output of luminaires as well as affecting the glare and appearance of the units. A committee of the N.E.L.A. prepared a specification for the test and inspection of glassware, for the purpose of grading and providing a closer approach to uniformity.

The lamp manufacturers continued their practice of holding schools of a week's duration which are attended principally by central-station lighting men.

The Edison Lighting Institute constructed an exhibit to illustrate the fundamentals of electrical advertising and the function of light in making a city attractive.

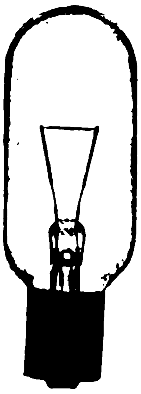

Fig. 137. Horizontal Coil-filament Lamp for Film Sound Recording

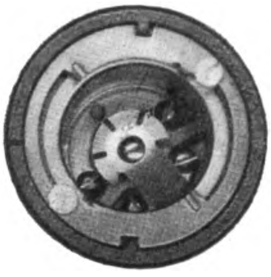

Fig. 138. Mogul Prefocusing Socket

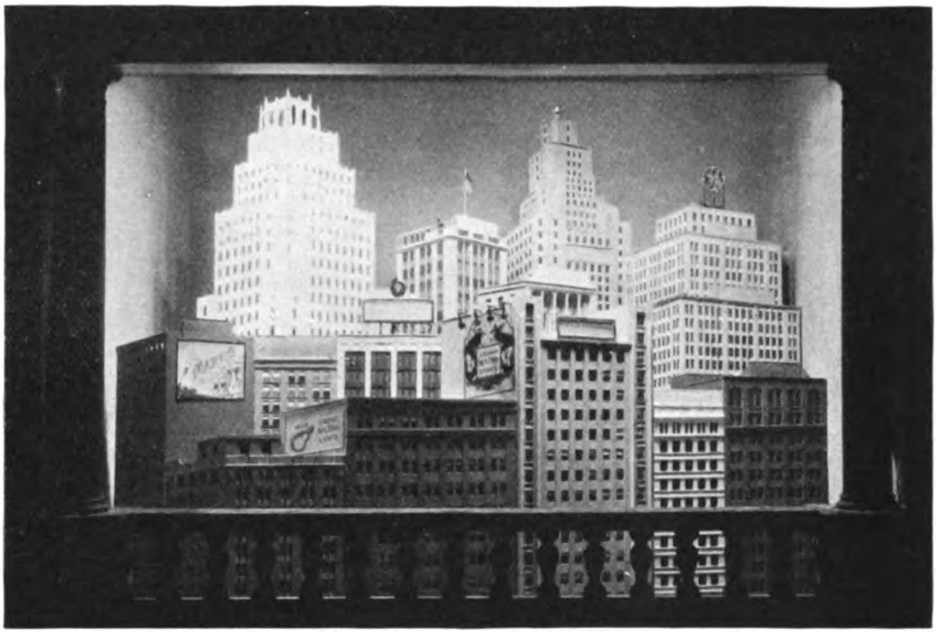

Fig. 139. Sign and Exterior Decorative Lighting Demonstration at the Edison Lighting Institute; Daytime View

The spectators have the impression (Fig. 139) that they are on the roof of a high building overlooking a typical American city while the entire cycle of the day and night passes before their eyes, from the first rosy tint of the rising sun to the twinkling stars and the crescent moon shedding its light over the scene. During the course of the action a severe storm comes up with its rapidly moving clouds, flashing lightning, falling rain, and terminating rainbow.

Ingenious wiring makes it possible for the lecturer to control all these effects from one point.

A massive fixture (Fig. 140) intended primarily for the offices of executives is so constructed that from a desk the level of illumination may be controlled and concentrated beams of light may be directed to charts, illustrations, etc., on the walls.

The decorators and designers in France first conceived the idea that electric lighting was a new medium and should not be treated in the so-called classical style. They introduced a new note into modern design and have continued the development of the basic idea with remarkable success. American architects, decorators, and designers have found some of the ideas (Figs. 141 and 142) of practical value and have brought forth new examples of the application of the so-called modernistic principles. These are naturally confined to the essentially decorative type of interior, the high-class shop, restaurant, theatre, hotel, and home.

The standard screw base with its bulk made it difficult to design neat, compact light ornaments and fittings but the intermediate screw base now applied to a new tubular lamp makes it possible to construct many shapes of lighting devices hitherto considered impractical. A number of new forms of light ornaments (Figs. 143 and 144) have appeared, and there is an increasing interest in this novel use of light for decoration.

Fascinating results are obtained when bushes, shrubs, and gardens are floodlighted at night. Many gardens represent a large investment in time and money, and the practice of making their beauty visible at night by skillfully applied artificial light, sometimes in color, is rapidly growing.

A new radio panel lamp for lighting the dials of radio sets operated from the lighting circuit is rated at 2½ volts, 0.45 amp., and has a miniature screw base.

Street Lighting

Intensive white-way lighting, *i.e.*, street lighting delivering from 300 to 2000 lumens per foot, was inaugurated in 1916 by the "Pathway of Gold" in

San Francisco. Since that time, street illumination of this character has been adopted by more than 50 cities in the United States, the additions during the year including the cities of Detroit (Mich.), Kansas City (Mo.), Oakland (Calif.), Houston (Tex.), and Washington (D. C.).

Washington Boulevard, Detroit, became the best lighted street in the world with a new five-light ornamental illumination system. The lighting standards, placed in double rows along the parkway in the middle of the street (Fig. 145), are of record size, giving an illumination per pole of 10,500 candle power, which exceeds State Street, Chicago, heretofore the best lighted street, by more than 1000 candle power. This was the first installation to utilize large Mazda lamps in groups of five to a standard.

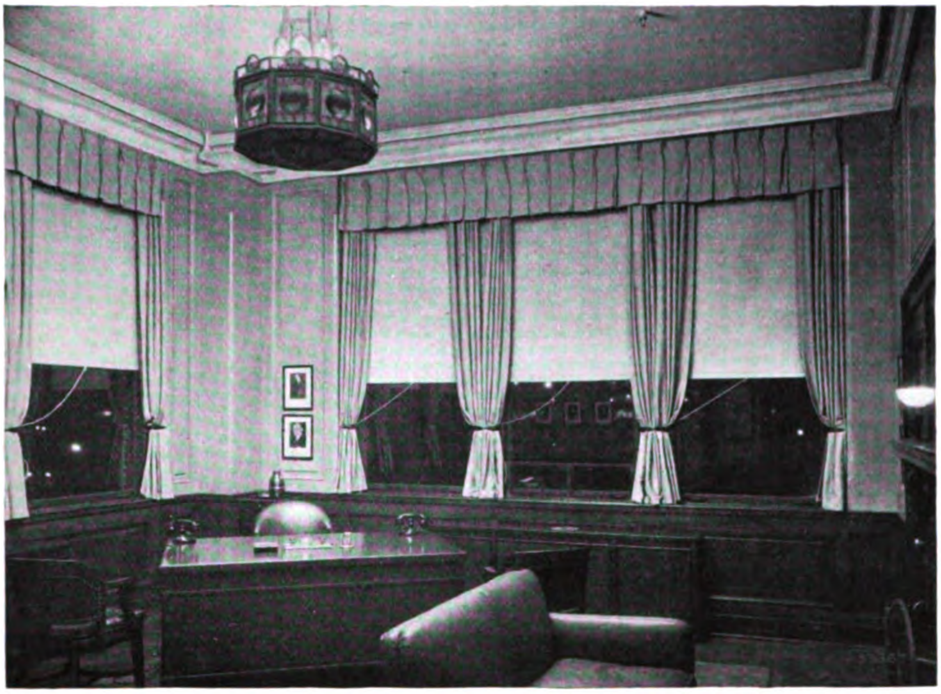

Fig. 140. Office Fixture Design for Desk Control of Illumination Level

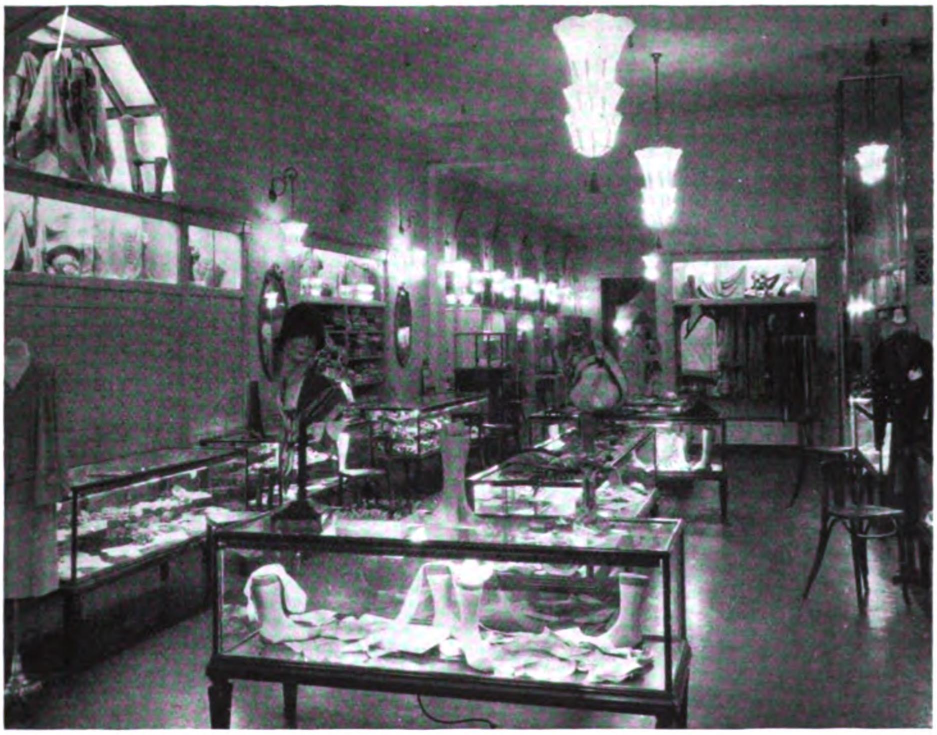

Fig. 141. Modernistic Lighting for Merchandise Display

Each standard has five units, 24 by 36 in. in size, each equipped with a 1000-watt 2100-candlepower incandescent lamp mounted on ornamental pole 32 ft. in height. This equipment gives approximately 2000 lumens per lineal foot of street.

A new bi-symmetric rippled-bowl refractor was produced which has a distribution of light suitable for residential and highway lighting. The inside of the refractor (Fig. 146) is made up of prisms, while the outside surface is rippled.

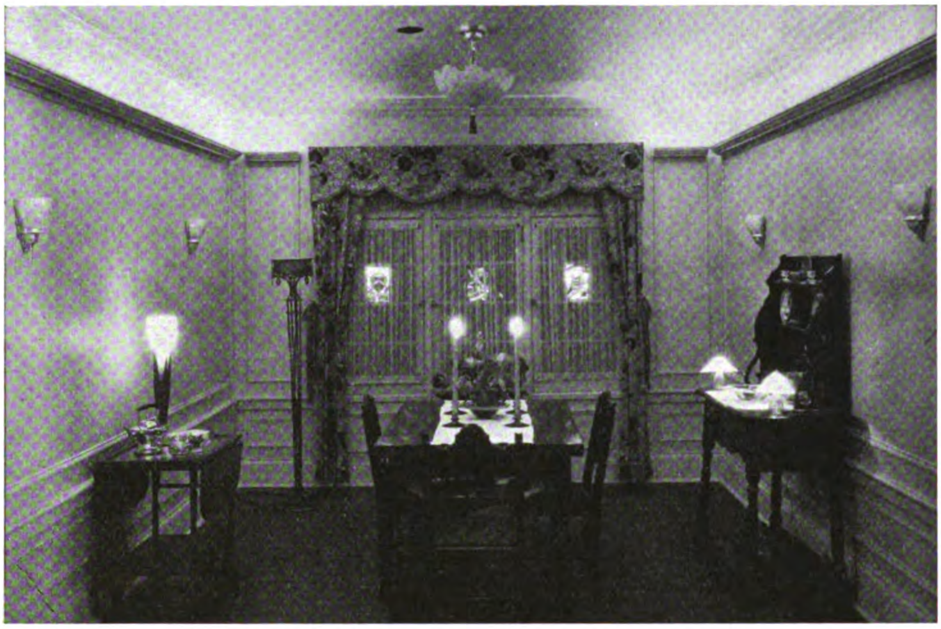

Fig. 142. Example of Indirect Cove Lighting for Both Illumination and Decoration of Room

To meet the demand for a constant-current transformer with a unity power-factor primary at full load, an extension was welded on the standard 10-kw. transformer tank (Fig. 147) and capacitors installed in the compartment so made. More than 100 of these are already in service and 15-kw. and 20-kw. sizes were designed on the same operating principle.

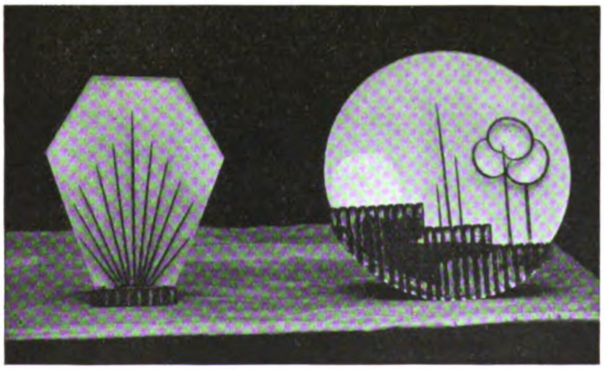

Fig. 143. Modernistic Types of Lighting Devices Made of Wrought Iron and Diffusing Glass

Motor-vehicle Lighting

A uniform motor-vehicle code was introduced in the legislatures of more than twenty states. It was designed to serve as a guide to secure, as far as possible, uniformity in motor-vehicle regulations.

Tentative specifications for the laboratory test for approval of motor-vehicle head lamps were prepared under the joint sponsorship of the Illuminating Engineering Society and the Society of Automotive Engineers. They represent an advance in requirements over previous practice and cover particularly headlighting equipment of the depressible beam type.

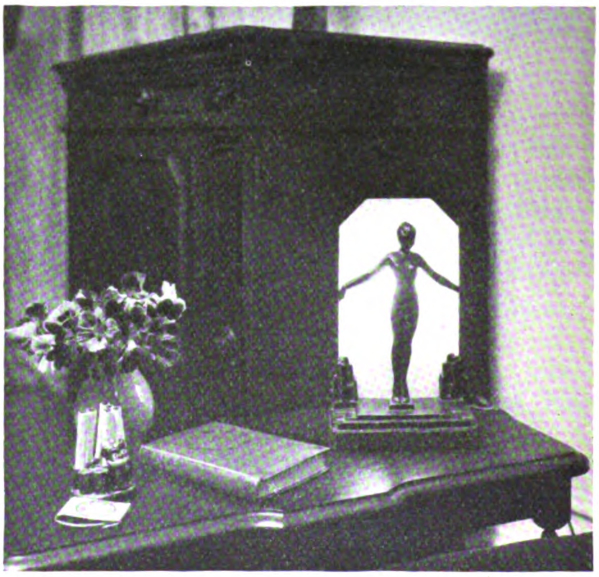

Fig. 144. Ornament with Statuette Revealed in Silhouette Against a Luminous Background

Considerable progress was made in the design of headlamps relatively less sensitive to change in filament position, and the trend in design is toward fixed-focus construction with a very simple aiming mechanism to lower or raise the top of the beam.

Traffic Control

A new impulse traffic-signal control system of exceptional flexibility was developed which utilizes a timing device for each interconnection with a central controller and cable interconnection to allow the total time cycle to be varied. This practically varies the speed of progressive movement through any area. Incidental features are the ability to reset the system automatically, and central control such as central shutdown of lights, remote fire control, etc.

The system provides means for at any time resetting the controller at each intersection to permit movement on the main and side streets to correspond to the actual proportions of traffic at that intersection and for initially setting the controllers "in step" to permit a progressive flow of traffic through the area at a given speed. Centrally operated means are provided for varying this speed of movement through a wide range.

The equipment necessary includes an impulse-transmitter timer at the central point, an impulse-receiver timer at each intersection, either automatic or combined manual and automatic, multi-conductor cable between the transmitter and receivers, and between the signals and controllers at each intersection, and the necessary signals.

The impulse-receiver timer (Figs. 148 and 149) is essentially a synchronous-motor timer with the motor element replaced by a double-solenoid "walking-beam" driving element, the operation of which depends upon the energizing of each solenoid alternately from a central control source. The speed of operation of this controller depends upon the rate at which the alternate solenoids are energized from the main transmitter. Each coil is wound for 110 volts, 60 cycles, alternating current, and takes 8 to 11 watts and $\frac{3}{10}$ amp. operating and 16 to 20 watts and $\frac{6}{10}$ amp. inrush. These coils will operate on plus or minus 10 per cent rated voltage. The timer is rated 5 amp. 110 volts alternating current.

The impulse-transmitter timer (Figs. 150 and 151) is used as a main transmitter at the central control point of an impulse-control system to keep all receiver timers throughout the system operating at the same speed, to vary the speed of operation of all the receivers, and to act automatically to resynchronize all receivers once each cycle.

The timer consists of a standard induction timer-motor mechanism having a standard shaded-pole-piece speed-variation adjustment within a 2 to 1 range, and to further increase the total time cycle range to give a 4 to 1 adjustment this motor mechanism is connected to a front-dial adjusting 2-to-1 gear-shift mechanism. The motor mechanism operating through this gear shift, drives a pair of insulation-composition cams which operate alternately to open and close a pair of silver-tipped contacts, the making and breaking of which at any established rate results in the alternate energizing of the two solenoids operating the receiver at each intersection.

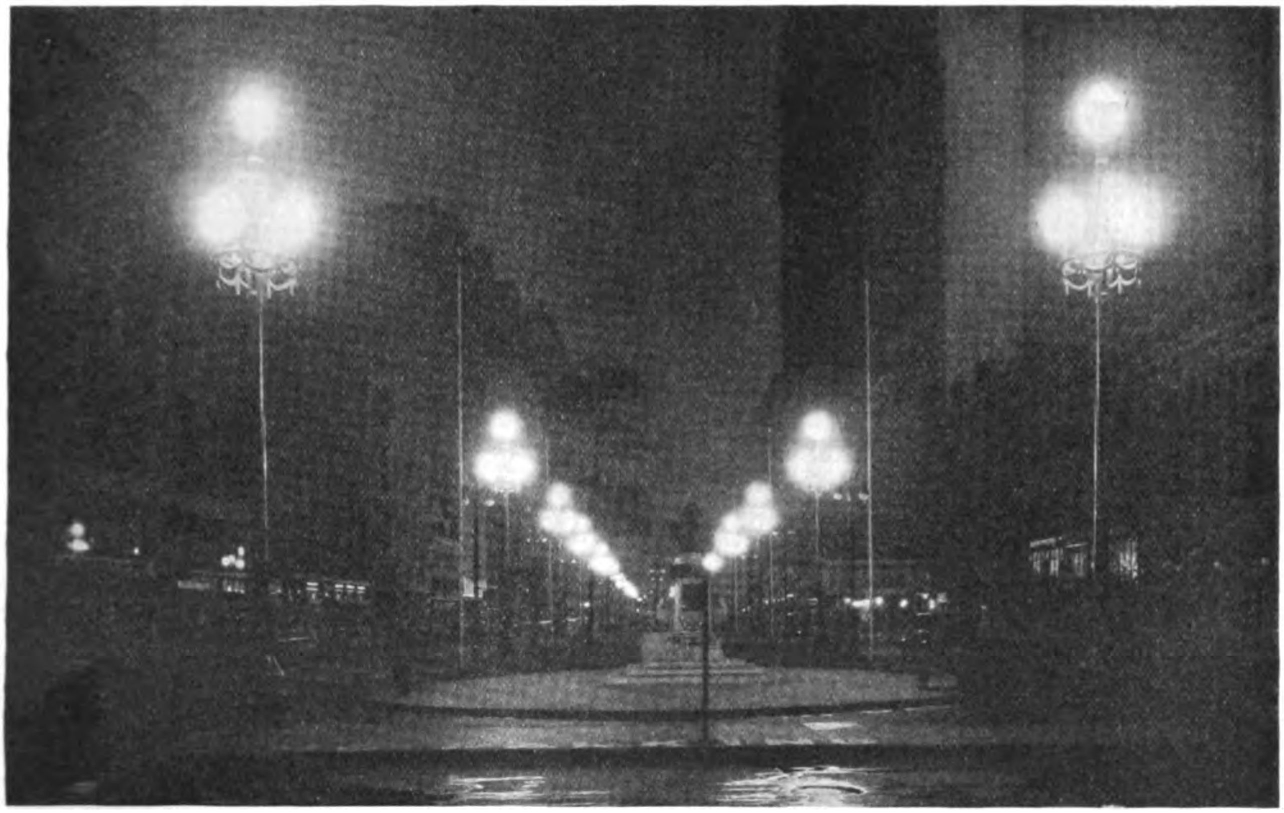

Fig. 145. Washington Boulevard, Detroit, with Five-lamp Lighting Standards

An increase of the rate of opening and closing of the transmitter contacts results in an increase in the speed of operation of each receiver timer, and similarly a decrease in the rate of make and break at the transmitter results in a decrease in the speed of operation of each receiver timer.

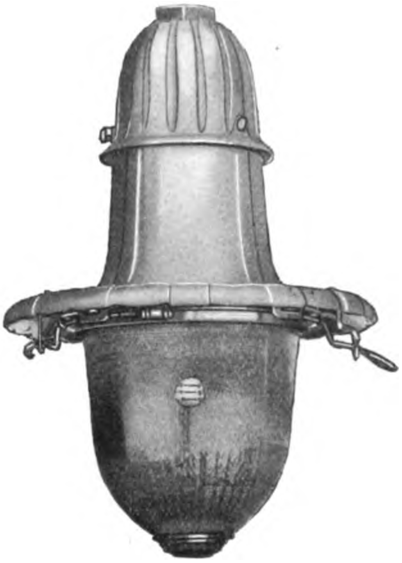

Fig. 146. Bi-symmetric Rippled-bowl Refractor

One of the most baffling traffic control problems is that of controlling traffic at isolated intersections, at which the volume and distribution of traffic on the main and side streets varies so greatly that a standard automatic controller is not applicable.

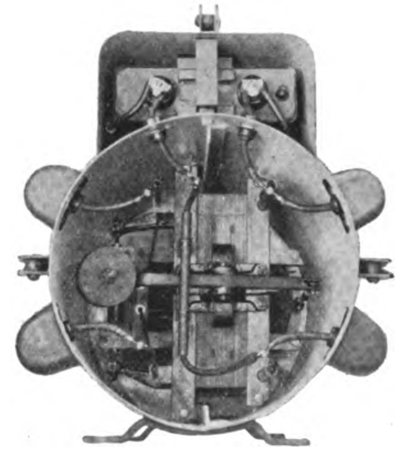

Fig. 147. Constant-current Transformer Showing Location of Compartment for Capacitors

A traffic-operated controller (Fig. 152) was designed to meet these conditions, actuated by a push button or by the sound of a horn and responsive to traffic moving through an intersection and hence sensitive to volumetric fluctuations and distribution of the traffic at that intersection. When traffic is waiting on the side street, the control gives the green signal to the side street; but when there is no traffic waiting on the side street, the main-street traffic is given the green indefinitely. The main-street traffic is never held up and stopped unless there is traffic on the side street.

The controller is so arranged that a green signal will continue to show indefinitely to the main-street traffic, and a red signal to the secondary-street traffic until such time as vehicles or pedestrians on the secondary street desire to enter or cross the main street.

Any time that side-street traffic demands the green signal, either by the sounding of a horn or the operation of a pedestrian button, an automatic timer operates to give a definite proportion of time to the side street, after which it gives a definite proportion of time to main-street movement. During this latter period, side-street traffic demanding the green signal receives only an amber warning in addition to the red, an indication that the request for the green has registered and will be granted as soon as the main-street right-of-way period is over.

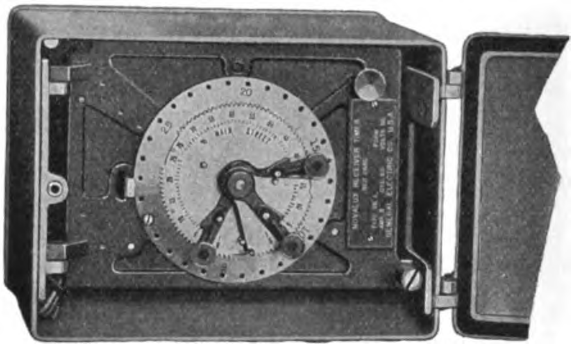

Fig. 148. Front View of Impulse-receiver Timer

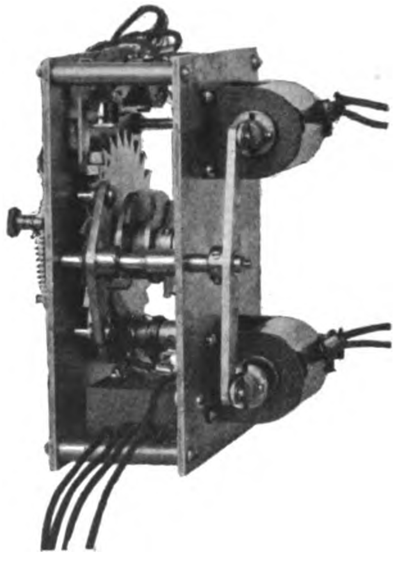

Fig. 149. Impulse-receiver Timer Mechanism

However, after this short main-street right-of-way period, and with the green set to show on the main street indefinitely, any vehicle or pedestrian coming up to the intersection, operating the control, and receiving an amber signal, will receive the green light immediately.

The lengths of time allocated to both the main and side streets right-of-way periods, the amber signals, and the total cycle of operation of the timing mechanism are both adjustable through wide limits by means of self-locking adjusting dials located on the face of the main controller.

Aviation Lighting

The mileage of lighted airways in the United States will be increased to 12,000 by the middle of 1929 when the present program of the Department of Commerce is completed. These airways (operated by the Department) will have 24-in. rotating beacons at ten-mile intervals with their auxiliary on-course lights flashed by the beacon mechanism. The on-course lights are equipped either with amber or red front-door glasses, the former placed at intermediate fields about 30 miles apart and the latter at beacons where no landing place is available.

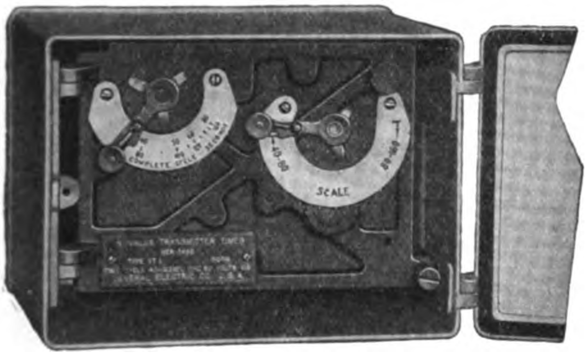

Fig. 150. Front View of Impulse-transmitter Timer

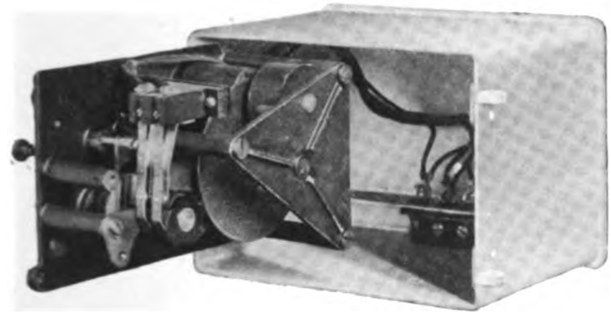

Fig. 151. Impulse-transmitter Timer Mechanism

At intermediate fields, boundary lights (Fig. 153) mark the borders of the field and are provided with either frosted lamps or frosted enclosing globes to avoid glare in the eyes of pilots.

In order to assure the continued operation of landing field floodlights, they were equipped with a triple automatic lamp changer (Fig. 154) which instantly brings a new lamp into focus in the event of a burnout.

An improved type of floodlight using a multiplicity of lamps projects the light so as to give a wide diversion in the horizontal plane with a moderate vertical spread. Fourteen 1500-watt 32-volt lamps arranged in a straight line are used (Fig. 155). The reflectors are of glass, polished and silvered and are parabolic "troughs," the focal line being arranged horizontally at the line through the lamp filaments. The reflectors, each 15 in. wide and 36 in. high, are separately adjustable with the filament line. The front door is of heat-resisting glass, and is easily replaceable.

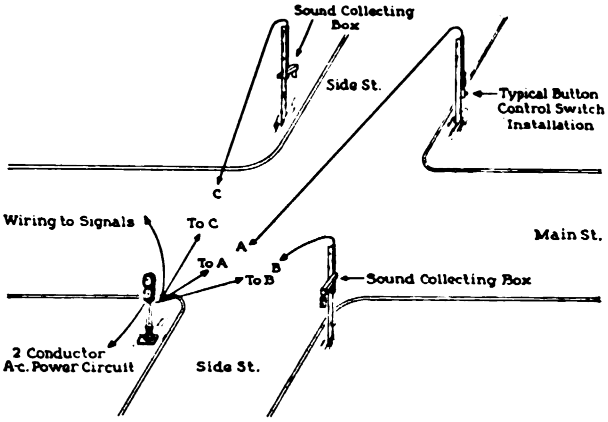

Fig. 152. Schematic Wiring Diagram for Traffic-operated Control

The heat from the lamps is dissipated by circulating the air inside the unit and radiating it from the enclosing casing. The unit combines high candle power, wide beam spread, and light weight with portability and adaptability to remote control.

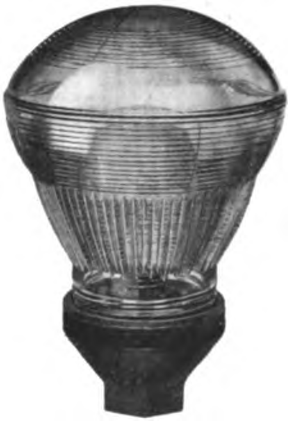

Fig. 153. Boundary Light for Intermediate Fields

Research work was continued to determine the type of light best suited for airport use in foggy weather and to develop obstacle lights for placement on power transmission lines.

Near the close of 1928 three developments resulting from research work were announced, which, although they do not refer to lighting, are given brief mention here on account of their practical value to aviation:

The first was a method of depth-sounding in the air to enable aviators to determine their altitude with reference to the ground over which they were passing. This is accomplished by sending out radio waves from the airplane, which are reflected from the ground and received by the airplane. The frequency of these impulses changes cyclically with changes in the altitude of the plane and suitable instruments permit a conversion of these changes into altitude readings. It is obvious that this method will be of maximum value when flying at night or through fog.

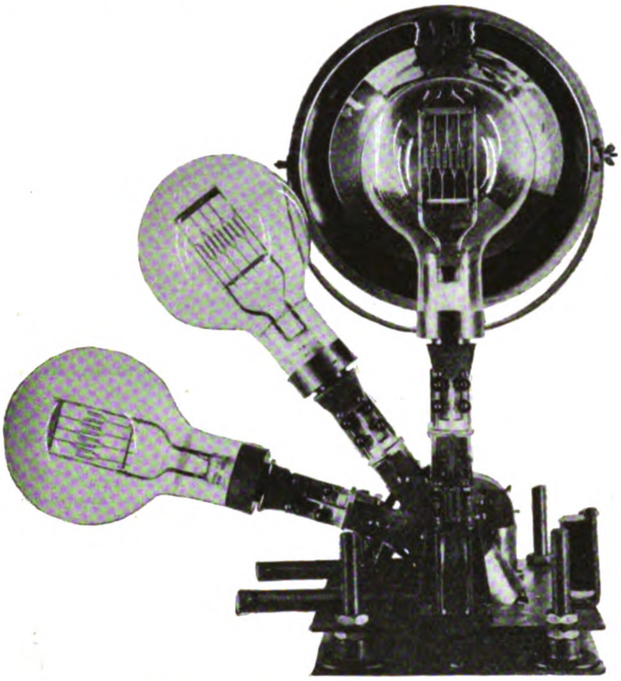

Fig. 154. Triple Automatic Lamp Changer

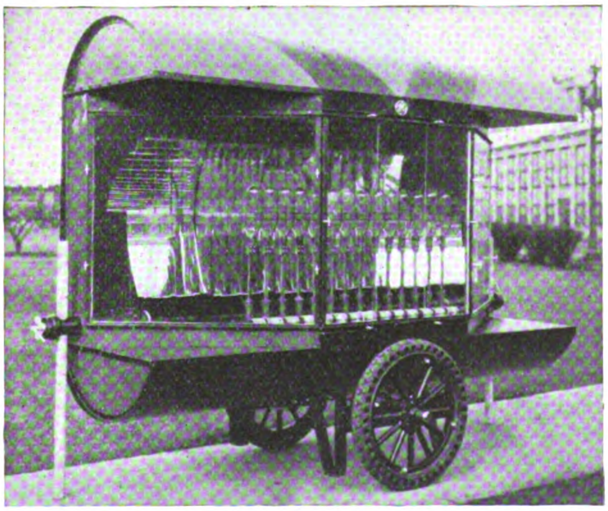

Fig. 155. Multiple-lamp Airport-field Lighting Projector

The second is a magneto compass which weighs less than one-fifth as much as does the present type of earth-inductor compass. It is of the rotating armature type and driven by a small propeller, and requires at least one-half horsepower less energy for its operation than existing propeller-actuated types.

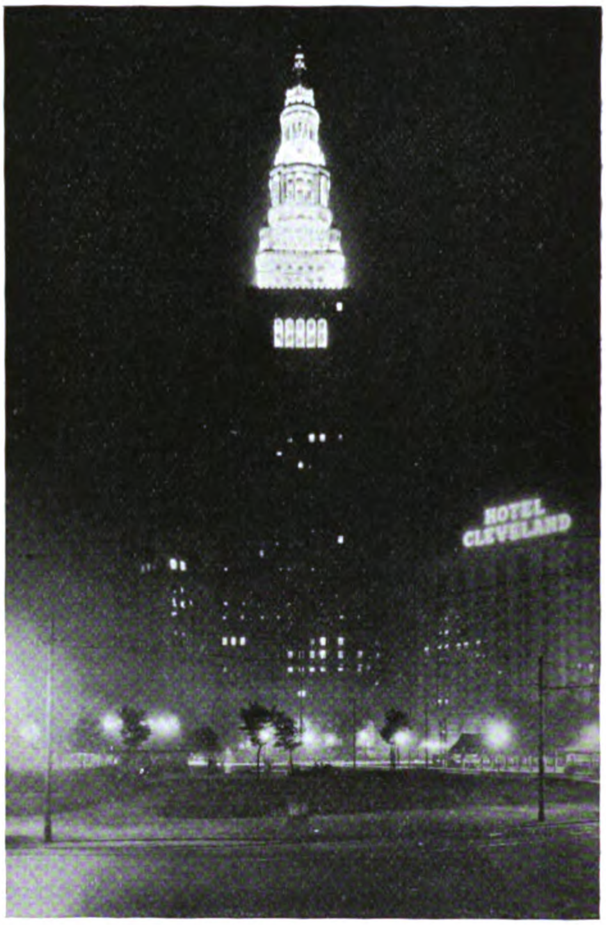

Fig. 156. Cleveland Union Terminal Building Tower, Floodlighted

The third development is that of a new means for measuring the amount of gasoline in airplane tanks, the instruments being actuated by electrical impulses transmitted from diaphragms located in the airplane

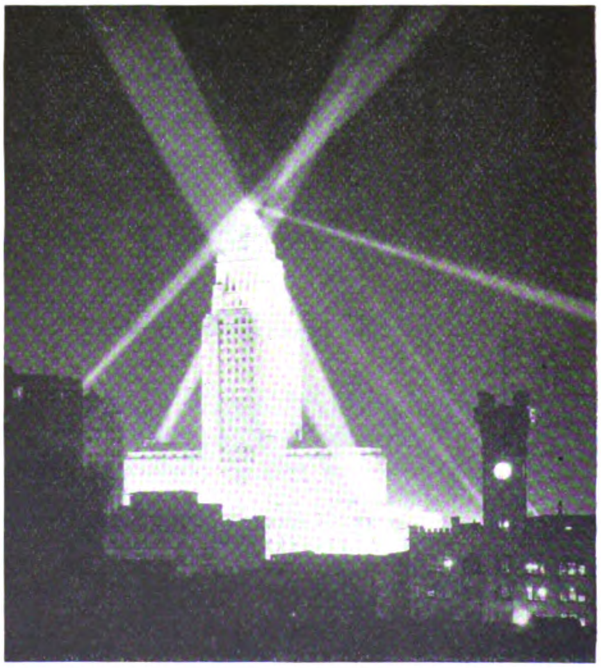

Fig. 157. Los Angeles City Hall Illuminated with Temporary Floodlighting Equipment

tanks. The result is a practical weighing of the gasoline and tests so far indicate that the accuracy thus obtained is better than 99 per cent.

Floodlighting

There was an increased use of floodlights for the illumination of athletic grounds and stadiums to permit the holding of practically every type of open-air athletic contest at night. There was also a notable increase in the number of illuminated fountains; and the demand for this form of nocturnal decoration resulted in the practical standardization of several sizes of fountains with complete specifications for masonry work, wiring, and projectors.

One of the outstanding floodlighting projects of the year is that of the Cleveland Union Terminal Building, which has a tower rising to a height of 710 ft. above the pavement.

The upper terraced section of the tower (Fig. 156), approximately 275 ft. in elevation, is lighted by a total of 220 floodlighting projectors installed upon the various parapets and ledges of the tower. They are equipped with lamps ranging from 200 watts to 1000 watts in rating and have a total connected load of approximately 140 kw. An average intensity of illumination of 15 to 21 foot-candles is produced upon the objective areas of the tower.

No colored light was employed, all relief lighting effects being obtained by white light. Careful attention was given to such factors as the elimination of objectionable shadows, the uniformity of light distribution, relief lighting, and maximum beam economy by means of diffusing and diverging glass doors for the projectors.

Very striking effects were obtained during the three-day celebration of the dedication of the Los Angeles new City Hall. The tower of this building is capped by the Lindbergh Air Beacon, which has a visibility range of between 50 and 60 miles. The illumination of the city hall during the celebration was accomplished by means of a temporary installation of batteries of floodlight projectors (Fig. 157).

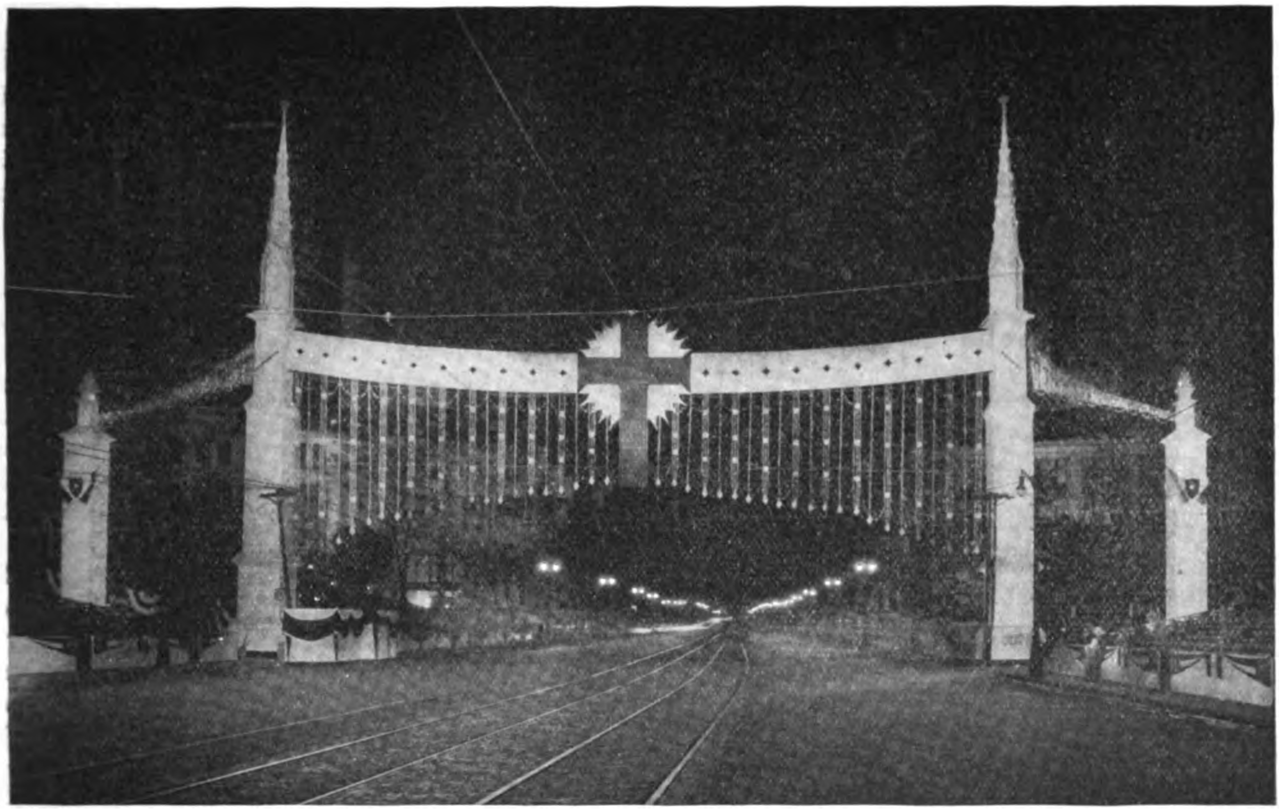

Fig. 158. Floodlighted Jeweled Arch at Knights Templar Conclave in the City of Detroit

An unusual example of decorative lighting was arranged for a conclave of the Knights Templar in the City of Detroit. It consisted of a jeweled arch (Fig. 158), 144 ft. wide, stretched on 75-ft. towers at the curbs, and flanked on either side by 35-ft. towers carrying the arch over the sidewalks.

The 26,000 glass jewels in the arch were illuminated by thirty-six 18-in. arc searchlights equipped with varied color screens and delivering an illumination of 540,000,000-beam candle power.

Progress in Radio Receiving During 1928

By DR. ALFRED N. GOLDSMITH
Chief Broadcast Engineer, Radio Corporation of America

PRIOR to considering the major characteristics of radio-receiver development during 1928, brief mention may be made of the situation as regards radio transmission and the regulation of broadcasting stations.

The country is still regarded as divided into five more or less arbitrarily defined zones. In each of these zones, stations (at least on the lower frequencies in the broadcasting band) are placed 50 kc. apart on the assumption that this will avoid excessive interference on most present receiving sets. As far as possible the separation between stations in adjacent zones is maintained at 20 kc. or, in certain instances, at 10 kc. These general principles of frequency allocation date back to 1923.

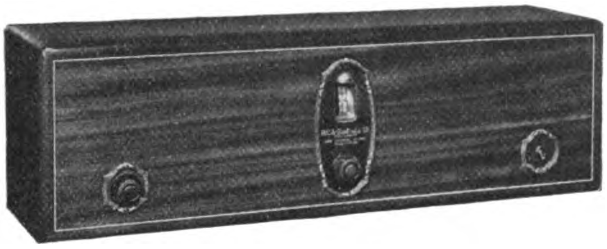

Fig. 1. A Tuned Radio-frequency Receiver for Alternating-current Operation, Radiola 18

The higher frequencies, particularly those between 1200 and 1500 kc. are still seriously overcrowded with frequent repetitions of the same frequency by stations in various portions of the country.

The Federal Radio Commission has given study to numerous problems of radio regulation during the year and has instituted a general reallocation of station frequencies, powers, and operating times, which it claims will improve radio service during 1929. No general reduction in the number of broadcasting stations has been attempted.

The problem of providing adequate frequency assignments for Canadian stations became acute during 1928. Canada claimed that its great area rather than its comparatively limited population should afford the basis for fixing its proportion of the total available broadcasting frequencies. The problem of an equitable division with satisfaction to both Canada and the United States cannot be said to have been solved as yet.

An interesting factor in the broadcasting situation has been a certain amount of television transmission in the broadcasting band. Despite the congestion in the broadcasting band, a limited number of stations have been authorized to carry on a certain amount of experimental television transmission on their regular wavelengths. Other stations have been authorized to experiment on higher frequencies or shorter waves.

General Receiver Trends

During 1928 the receiving sets placed on the market showed a high degree of refinement in details of circuit and mechanical design and construction as well as in the nature of their cabinets. The crudities which were found in the receivers of five or six years ago have disappeared, leaving a product which represents a stage in evolution comparable to that of the present-day automobile.

Perhaps the most interesting single trend during the year has been the widespread adoption by the radio industry of the dynamic speaker and of alternating-current tubes, both of which are features that have been offered to the American public previously but only by a limited group of manufacturers. Their general acceptance led to a greater ease of operation and maintenance of receivers and a marked improvement in the tone quality of the present-day receiving set.

The public lays an increasing stress on high fidelity of reproduction. Prospective purchasers of radio receivers pay close attention to the tone quality of the sets which are offered them and this often proves a determining factor in the selection of the receiver. Receiver-circuit design, as well as loudspeaker construction, have both evolved along lines which permit such high-quality reproduction.

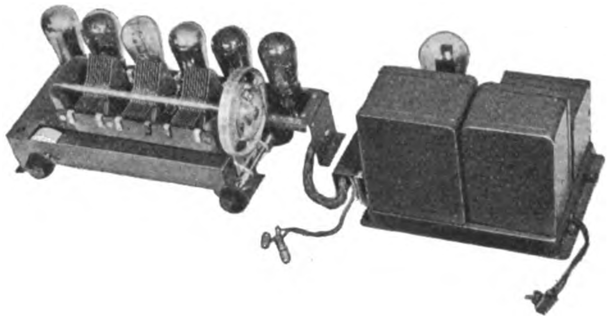

Fig. 2. Interior of Radiola 18

As is the case in any normally developing art which nears maturity, standardization is somewhat the order of the day. Test methods, and even the dimensions and certain external operating features of component parts of radio equipment, are increasingly subject to standardization by the Institute of Radio Engineers and the leading manufacturing associations in the radio field.

It will be gathered from the preceding that radio has reached a stage of stabilization which compares favorably with that of some far older industries and that, as a consequence, the production problems of the factories of responsible radio manufacturers have been considerably reduced in complexity and the hazards of production and sales are less than in previous years. The year of 1928 therefore had a healthy and tonic influence on radio development.

Receiver Circuits and Types

The first set introduced during 1927 to utilize the so-called alternating-current tubes, which made possible compact low-price receivers operating from the house-lighting circuit, was Radiola 17. During 1928 this set was superseded by the present type Radiola 18 which contains various refinements and improvements over the first models. Concurrently, the alternating-current tubes produced during 1928 were improved in quality, both as regards operating characteristics and life. It is clear that the alternating-current tube has become a permanent element in the radio field, having further successfully passed the test of its introduction in 1927 and of large scale use during 1928.

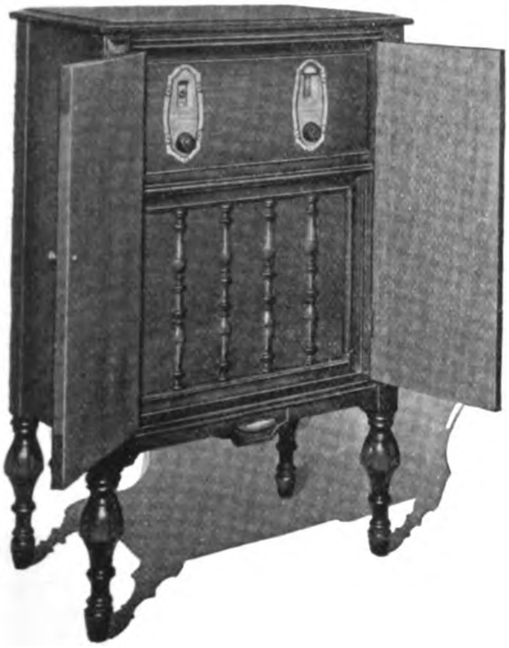

Fig. 3. A Cabinet Set Containing Tuned Radio-frequency Receiver and Loudspeaker, for Alternating-current Operation, Radiola 51

The popularity of this type of receiver has been such that the production has run into hundreds of thousands during 1928. As a significant result of this large-scale production, with its accompanying economies of manufacture, the unit cost of such receivers has been reduced 27 per cent. In radio, as in other fields, quantity production has become an important element in the prosperity of producer and consumer alike.

The increasing vogue of combined sets containing both receiver and loudspeaker housed in a single cabinet has led to the production of Radiola 51. Previously, Radiola 50, which was a cabinet combination of Radiola 17 and loudspeaker, was placed on the market (late in 1927). It is now being superseded by Radiola 51 of the same general type but further revised.

The floor-mounted cabinet in this type of receiver contains a Radiola 18 chassis with the well-known Model 100-A loudspeaker. Careful consideration must be given in such sets to avoiding any detrimental effect of the cabinet enclosure on the quality of reproduction to be obtained from the loudspeaker.

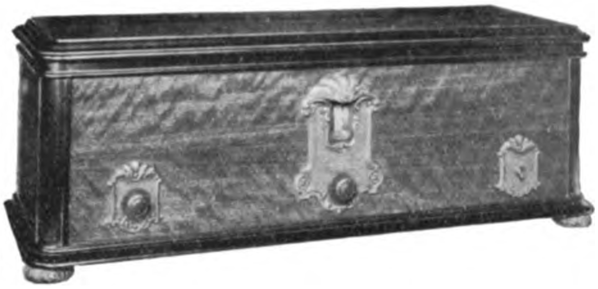

Fig. 4. An Alternating-current Superheterodyne Receiver, Radiola 60

Quantity production in the case of this receiver has also permitted a reduction of unit cost to the public of 33 per cent since initial production.

An extremely interesting and important step forward in broadcast receiving set development is the introduction to the public of the first model using the superheterodyne circuit to be equipped with the new alternating-current tubes. The new receiver referred to is known as Radiola 60, and the circuits which it employs are utilized in the so-called "60 series" of Radiolas (No. 60, 62, and 64).

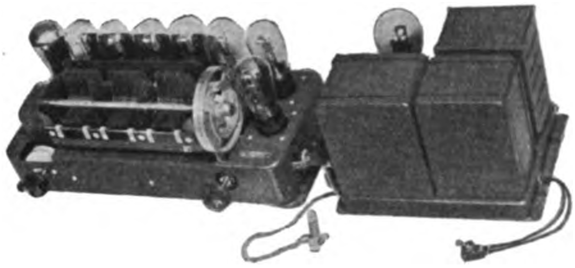

Fig. 5. Interior of Radiola 60, Showing Tuning Condensers, Tubes, and Power-supply Unit

Previous models of the superheterodyne circuit, while arranged for operation on the lighting circuit, nevertheless utilize the battery type of tube together with extensive rectifier systems. In contrast, the new models use the alternating-current tubes and thereby achieve increased compactness, greater simplicity, and markedly lowered costs.

At the same time it has become possible greatly to improve circuit-performance characteristics in

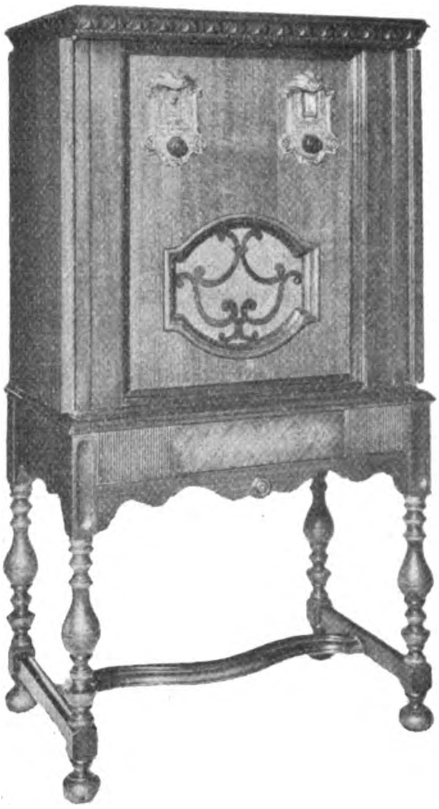

Fig. 6. A Cabinet Set Containing Alternating-current-operated Superheterodyne Receiver and Dynamic Loudspeaker, Radiola 62

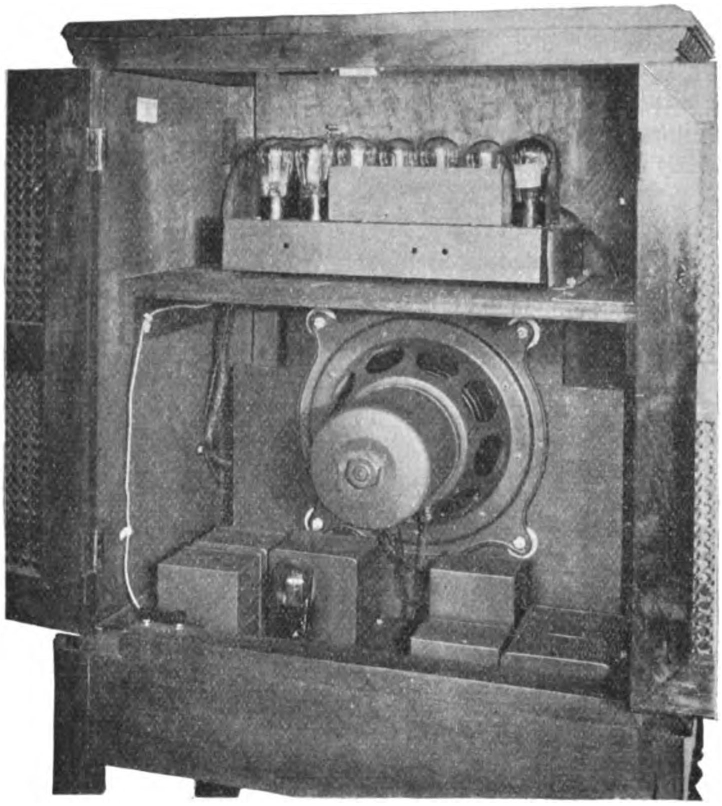

Fig. 7. Interior of Radiola 62, Showing Receiver Unit, Dynamic Loudspeaker, and Power Supply Units,

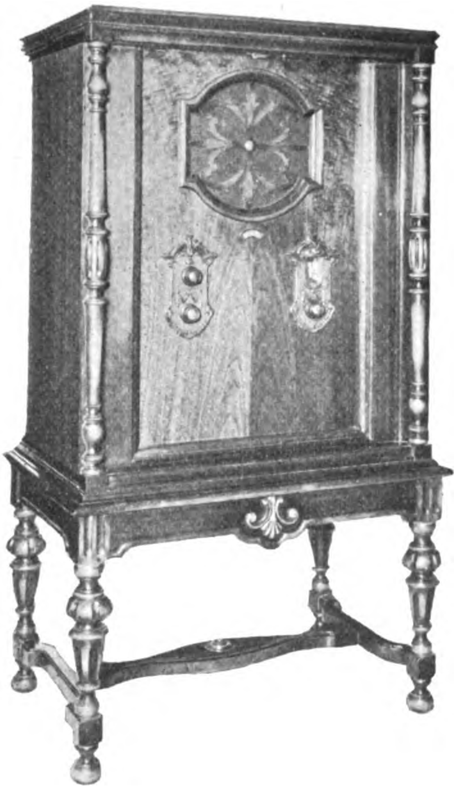

Fig. 8. A Cabinet Set Containing Alternating-current-operated Superheterodyne Receiver with Automatic Volume Control and Dynamic Loudspeaker, Radiola 64

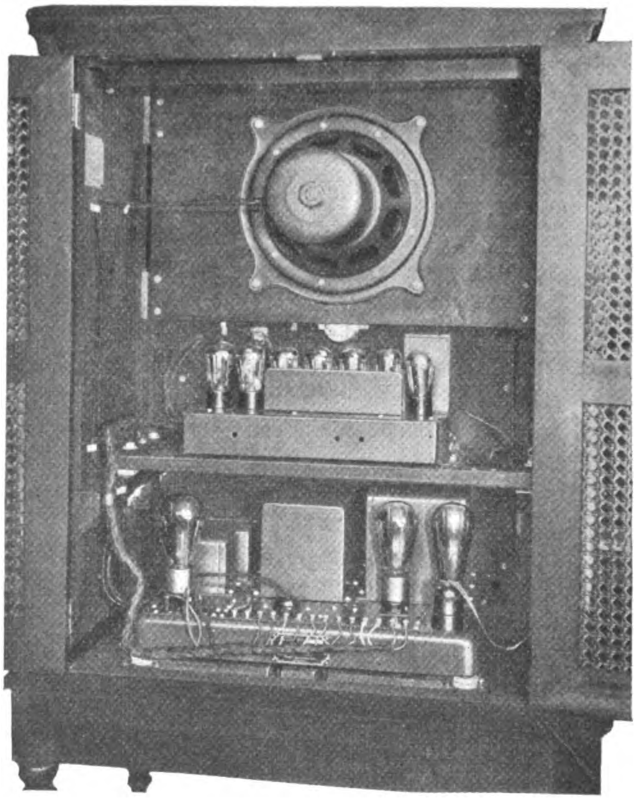

Fig. 9. Interior of Radiola 64, Showing Dynamic Loudspeaker, Receiver Unit, and Combined Power-supply and Power-amplifier Unit

receivers of this type. While a high degree of selectivity has been provided, the fidelity of reproduction has been maintained to an extent which has not hitherto been accomplished in broadcast receiving sets. This is particularly the case for the higher frequencies (above 4000 cycles) which contribute so much to the crispness of speech quality and to the naturalness of reproduction of vocal selections and orchestral instruments in the upper register. As most broadcast listeners are aware, in previous radio practice, high selectivity was generally accompanied by a loss of fidelity caused by marked reduction of the receiver (and loud speaker) response to the higher tone frequencies. This receiver includes another departure from previous general practice in that it utilizes only one stage of audio-frequency amplification, instead of two or more as had been previously used universally in receivers designed to operate loud speakers. It has been found that the elimination of one stage of audio-frequency amplification causes a substantial improvement in fidelity of reproduction.

Fig. 10. An Ornamental Type of Moving-iron-actuated Loudspeaker, Radiola 103 Loudspeaker

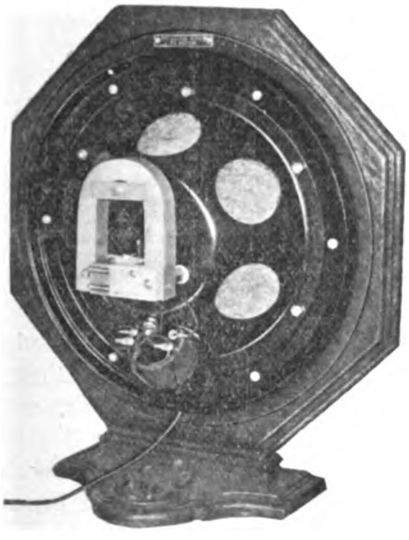

Fig. 11. Rear View of Radiola 103 Loudspeaker with Cover Removed, Showing Acoustic Treatment, Motor Drive, and Applied Filter

It is also interesting to note that the cost to the public of this receiving set has been very markedly less than that of previous receivers of the superheterodyne type. Production running into five figures resulted during 1928 and it is believed that the manufacture of superheterodyne receivers selling at a moderate price represents a distinct step forward in manufacturing technique.

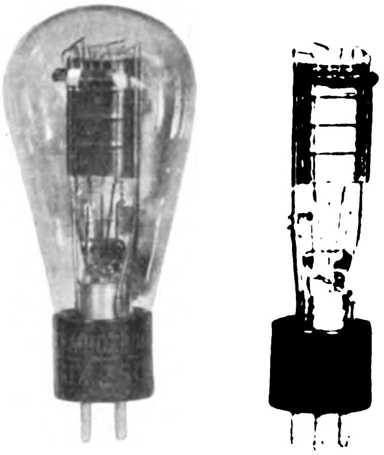

Fig. 12. A Power-amplifier Tube Having High, Undistorted Output, Radiotron UX-250

In the case of this receiver, as in other instances, there was felt a need for complete cabinet-enclosed outfits embodying this receiver and also the loud speaker. Radiolas 62 and 64 have been designed to meet this demand.

The former of these sets consists of a combination, in a single cabinet, of a Radiola 60 chassis with a new design of electro-dynamic loud speaker. This loud speaker is a redesigned and improved form of the loud speakers previously known as Models 104 and 105 which were described in earlier reviews on annual radio progress.

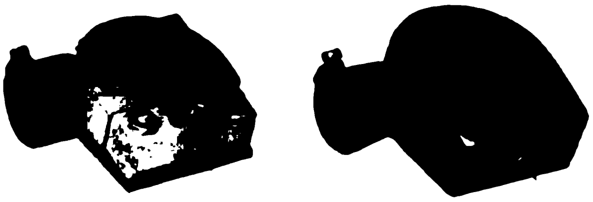

Fig. 13. Low-impedance Phonograph Pick-up with High Flexibility of Moving Element

It has been found possible in the new loud speaker to give very much better fidelity of reproduction than in previous models together with the same capability of supplying large volumes of sound without distortion, rattling, or other objectionable effects. In this receiver also the trend toward lower prices resulting from economy in quantity production have placed the Radiola 62 costs in a price range hitherto occupied by receivers of an entirely different class.

In the other cabinet receiver of this type, *viz.*, Radiola 64, an interesting policy has been adopted. It was decided to incorporate in one receiver all the available radio engineering expedients for producing a receiver which, it was specified, was to be as good in all operating characteristics as the art can now produce. Usually laboratory knowledge runs several years ahead of current practice but in this instance a successful attempt has been made to include all available information at the time of design in the construction of the receiver.

The chassis in this receiver is a Radiola 60 receiver with some modifications. The output stage, which determines the volume handling capability of a receiver, is a Radiotron UX-250 which has about four times the power capacity of the largest previous output tube widely sold to the public.

The chassis is further modified by the addition of the novel feature of automatic volume control. This feature operates to control the volume of sound delivered by the loudspeaker automatically after the volume control has been set by the user for the volume desired. After the volume control is once set, the receiver reproduces all broadcasting stations with that same volume regardless of the strength of the incoming signals. This feature also operates markedly to reduce the "fading effect" or "swinging" of signals caused by variation in transmission of the signals between the transmitting and receiving points. Another feature is the incorporation of a meter used to indicate the proper tuning of the receiver; *i.e.*, the tuning adjustment of the receiver is made with the aid of the indications on the meter, rather than by the loudness of the loudspeaker response, as in all previous receivers.

It will be noticed from the foregoing that the trend toward extreme simplicity of operation is fully exemplified in such receivers as these which represent the results of an orderly evolution away from the original complicated and delicate receiving devices of five or six years ago.

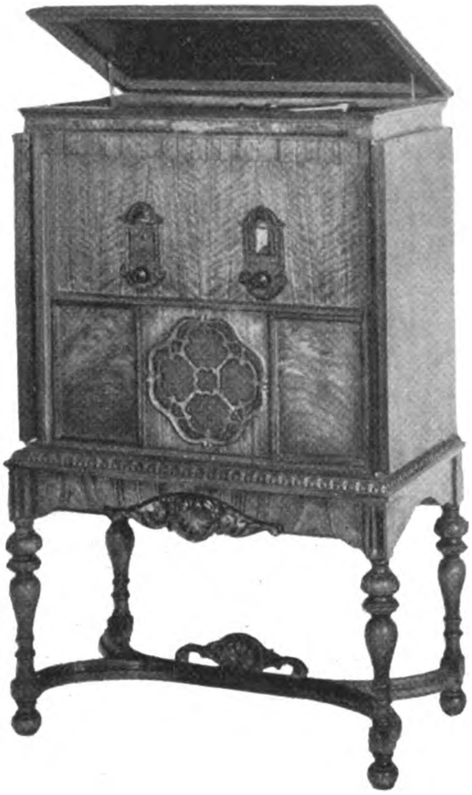

Fig. 14. Brunswick Radiola-Panatrope Combination (Radiola 62 and Panatrope Electric Phonograph)

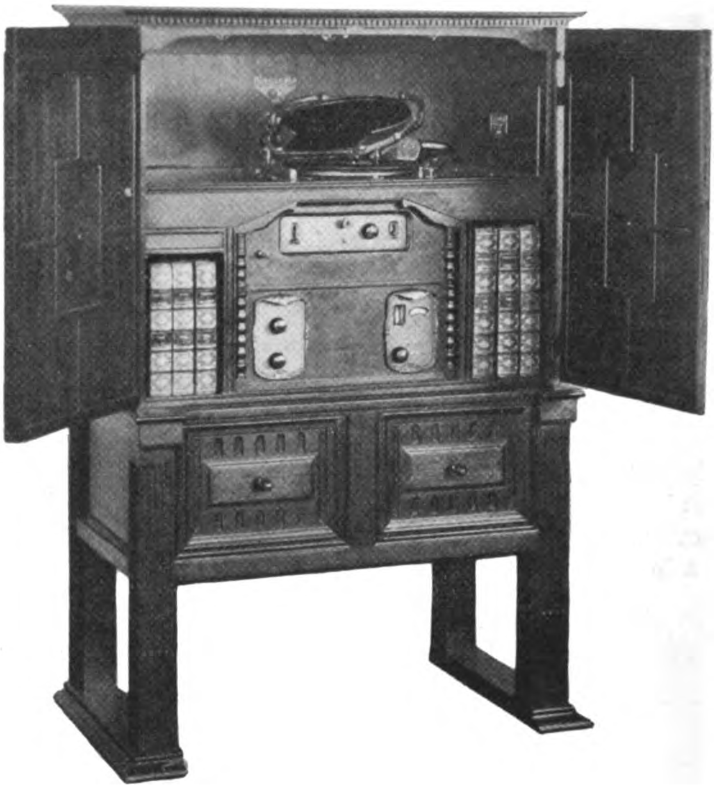

Fig. 15. Victor Radiola-Electrola Combination (Radiola 64 and Automatic Electrola, Electric Phonograph)

Loudspeakers

Improvements in receiver circuits having as their object increased fidelity of reproduction are necessarily futile unless the loudspeaker, which is the "neck of the bottle," is correspondingly refined to enable it to utilize fully what the receiving set can produce. Great stress has therefore been laid upon loudspeaker characteristics.

One of the earlier loudspeakers, *viz.*, Model 100-A, has continued throughout the year to be regarded as a fairly standard type. More than 300,000 of these reached the public during the year with a total production climbing rapidly toward the million mark since the introduction of this loudspeaker. As a result of quantity production in this case too, manufacturing improvements resulted, with a cost reduction to the public of about 23 per cent.

Radio has quite lost the laboratory aspects which made it an object of suspicion to the average

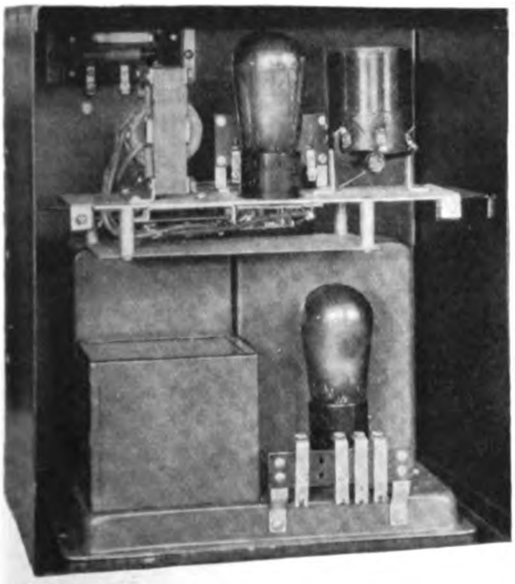

Fig. 16. Interior of a Master Radio-frequency Amplifier Unit of Centralized Radio Equipment

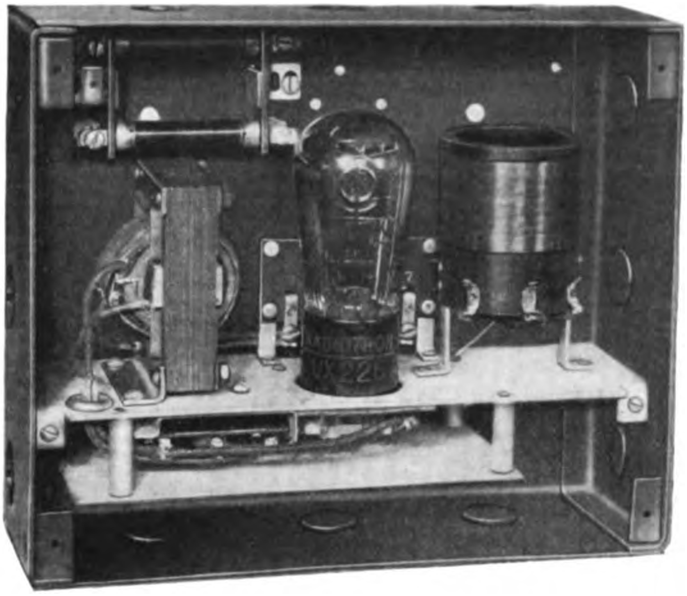

Fig. 17. Interior of Radio-frequency Amplifier for Individual Installations of Centralized Radio Equipment of the Radio-frequency Distribution Type

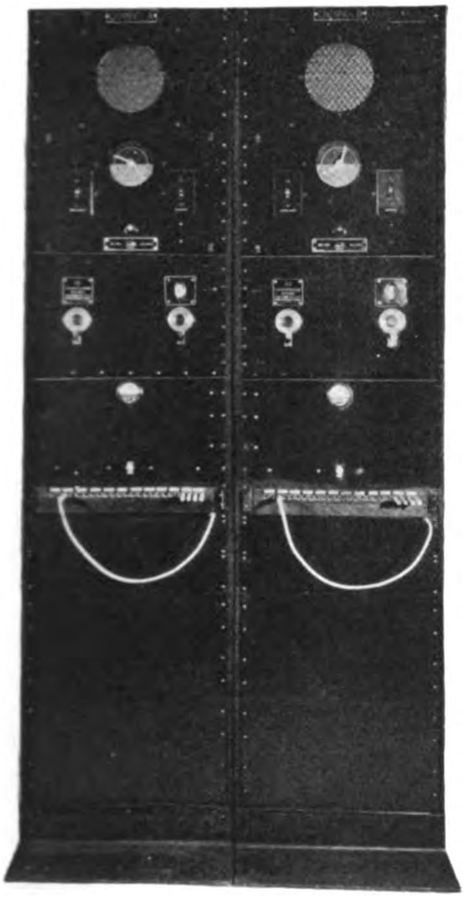

Fig. 19. Front View of Twin-channel Central Distribution Panels for Centralized Radio Audio-frequency Distribution Type

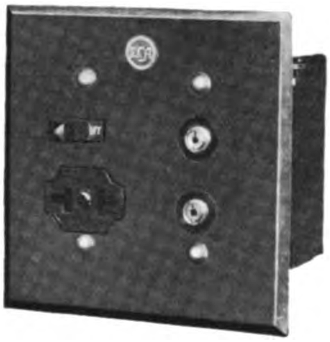

Fig. 18. Individual-apartment Outlet Box for Centralized Radio of the Radio-frequency Distribution Type

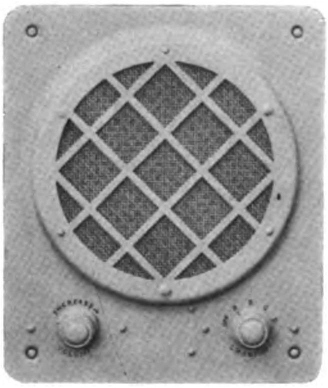

Fig. 20. Loudspeaker (Type 100-A) for Individual Installation of the Audio-frequency System of Centralized Radio

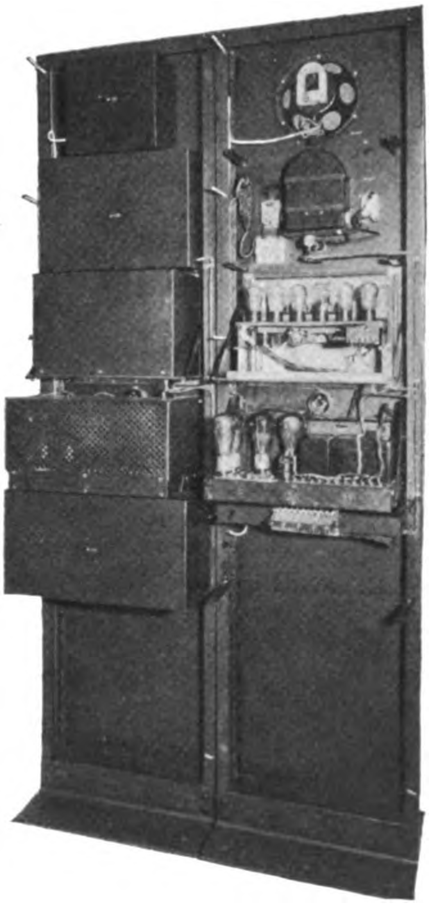

Fig. 21. Rear View of the Equipment Shown in Fig. 19

housewife a number of years ago. Attractive housings for for radio equipment are the order of the day. In accordance with this requirement, a loudspeaker mechanism similar to that of the Model 100-A loudspeaker has been embodied in the Model 103 loudspeaker. A wood casing with tapestry grille has been utilized, and the resulting loudspeaker, which has no resemblance to a mechanical device, has been extremely successful and has justified quantity production on a large scale.

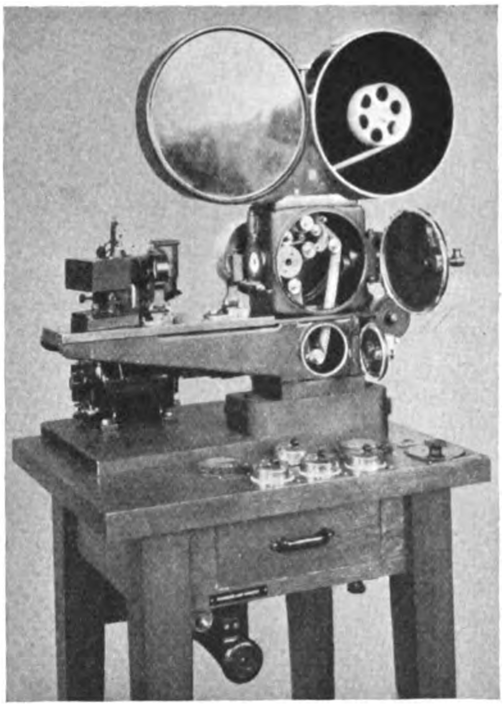

Fig. 22. RCA Photophone Sound Recorder for Sound-motion Pictures

Vacuum Tubes

The only vacuum tube introduced to the market since the date of preparation of earlier reviews on radio progress has been Radiotron UX-250. As previously stated, this is an audio frequency output tube having about four times the power capacity of the UX-210 which had previously been used in the most powerful sets. While the full output of such tubes is not required continuously, yet the increased range of distortion-free amplification of such tubes has enabled the user to reproduce orchestral music, singing, and even speech with considerably increased naturalness. A full orchestra in a great climax invariably sounds artificial if the output volume is limited too severely. For this reason, such output tubes as Radiotron UX-250 may be expected to have increased popularity as time goes on.

Electric Phonograph

The development of the electric phonograph has run somewhat parallel with that of radio receiving sets.

An improved phonograph pick-up was produced during the year. Its novel features are low impedance and considerably greater flexibility of the moving element. The latter feature leads to greatly increased life of phonograph records.

Typical examples of highly advanced combined electric phonograph and radio combinations are shown in the illustrations in this article. They include combinations of the most modern radio receivers and electric phonographs utilizing to the full the output capabilities of the available Radiotrons and the fidelity of reproduction of the dynamic loudspeakers. It is believed that the evolution of the phonograph has been greatly furthered by electric reproduction processes.

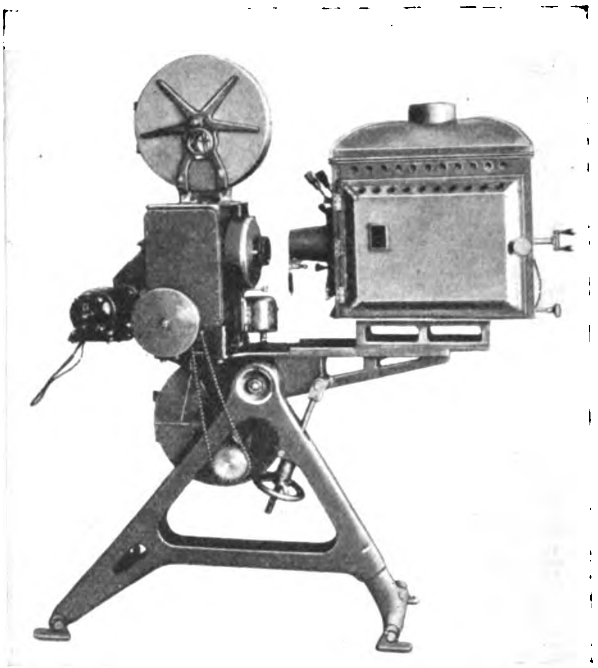

Fig. 23. RCA Photophone Projector (Type P-2) for Sound-motion Pictures

Centralized Radio

An important step forward in radio service to the public is its extension to certain large groups of transient or special types of listeners as well as the purveying of radio entertainment on a large scale to families living in apartment houses.

Specific instances of the type of service in question are radio reception for patients in hospitals, for guests in hotels, and for tenants in apartment houses. There has been developed and placed on the market during 1928 a type of centralized radio equipment which simplifies radio reception to the utmost for the listener. All receiving equipment, together with amplifiers, distributing panel for various circuits, volume-indicating devices, monitoring loudspeakers, and time clocks for turning the receiving equipment on and off at predetermined times have been mounted on one panel. Such a panel constitutes a "single-channel" receiver, capable of furnishing high-quality radio entertainment from one station to a large group of listeners each provided with his own loudspeaker or head set, as may prove more convenient.

By assembling two or more such panels, running corresponding sets of wires throughout the structure in which the radio programs are distributed, and providing a small channel-selector switch at each installation, it becomes as readily possible to provide multi-channel service to each listener as single-channel service. It will be interesting to watch the development of this type of service in the large apartment houses now under construction and to study the development of what may be termed institutional broadcast reception in hotels, hospitals, and other places where large groups of individuals must receive reliable radio service from a limited number of stations without the necessity for installation of an individual radio receiver in the quarters of each of these individuals. Centralized radio is therefore a significant development which, it is believed, will find increasing application.

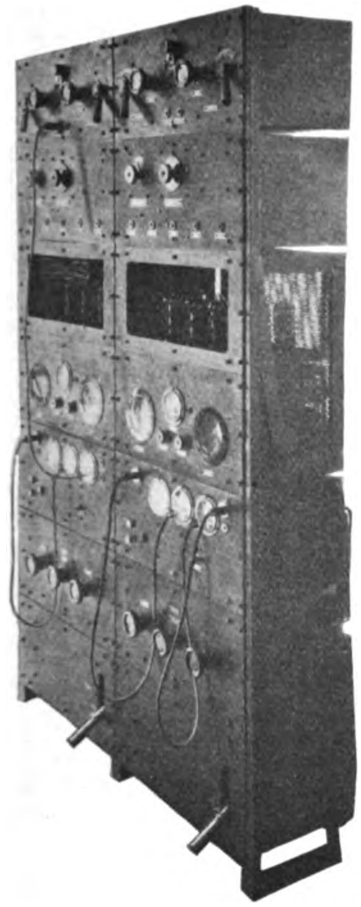

Fig. 24. RCA Photophone Power Amplifier (Type A) for Sound-reproducing System of Sound-motion Pictures

Sound-motion Pictures

A review of radio progress during 1928 would hardly be complete without at least brief mention of the progress in the sound-motion-picture field, which employs a number of instrumentalities very similar to those utilized in high-quality radio transmission and reception. Microphones and amplifier panels in the recording installation remind the onlooker forcibly of similar devices in the broadcast transmitting station. Audio-frequency amplifiers of high quality and corresponding loudspeakers in the theater or school bear a marked resemblance to the corresponding equipment employed for radio broadcast reception.

During 1928 RCA Photophone placed on the market a complete line of sound-motion-picture recording and reproducing equipment. The recording devices utilize galvanometer vibrators with mirrors of small dimensions which reflect a beam of light on to the moving film. The vibrations of the mirror and the reflected light beam (when passed through a suitable optical system) lead to a variable width film record. That is, the sound vibrations are represented by variations in the width of the "sound track" at the edge of the film.

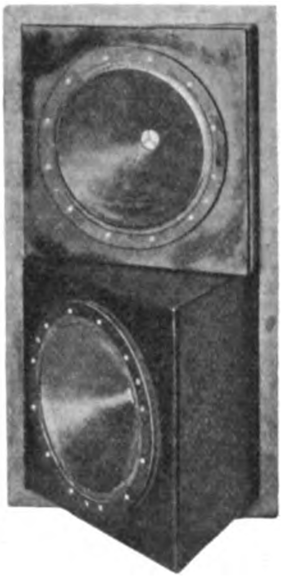

Fig. 25. RCA Photophone Cone Loudspeaker Assembly for Theater, School, and Church Auditorium Uses. Suitable combinations of these units are used in each installation

The reproducing equipment essentially consists of a combined picture-and-sound projector, an amplifier of considerable audio-frequency output, and banks of high-quality dynamic speakers suitably arranged for uniform distribution of the sound throughout the theater or auditorium. Recent types of such equipment show a degree of refinement in design and reliability of operation rather unusual for a new art.

Conclusion

The radio art during 1928 not only became more stable but branched out into several related entertainment fields, notably centralized-radio equipment and talking-motion-picture recording and reproduction.

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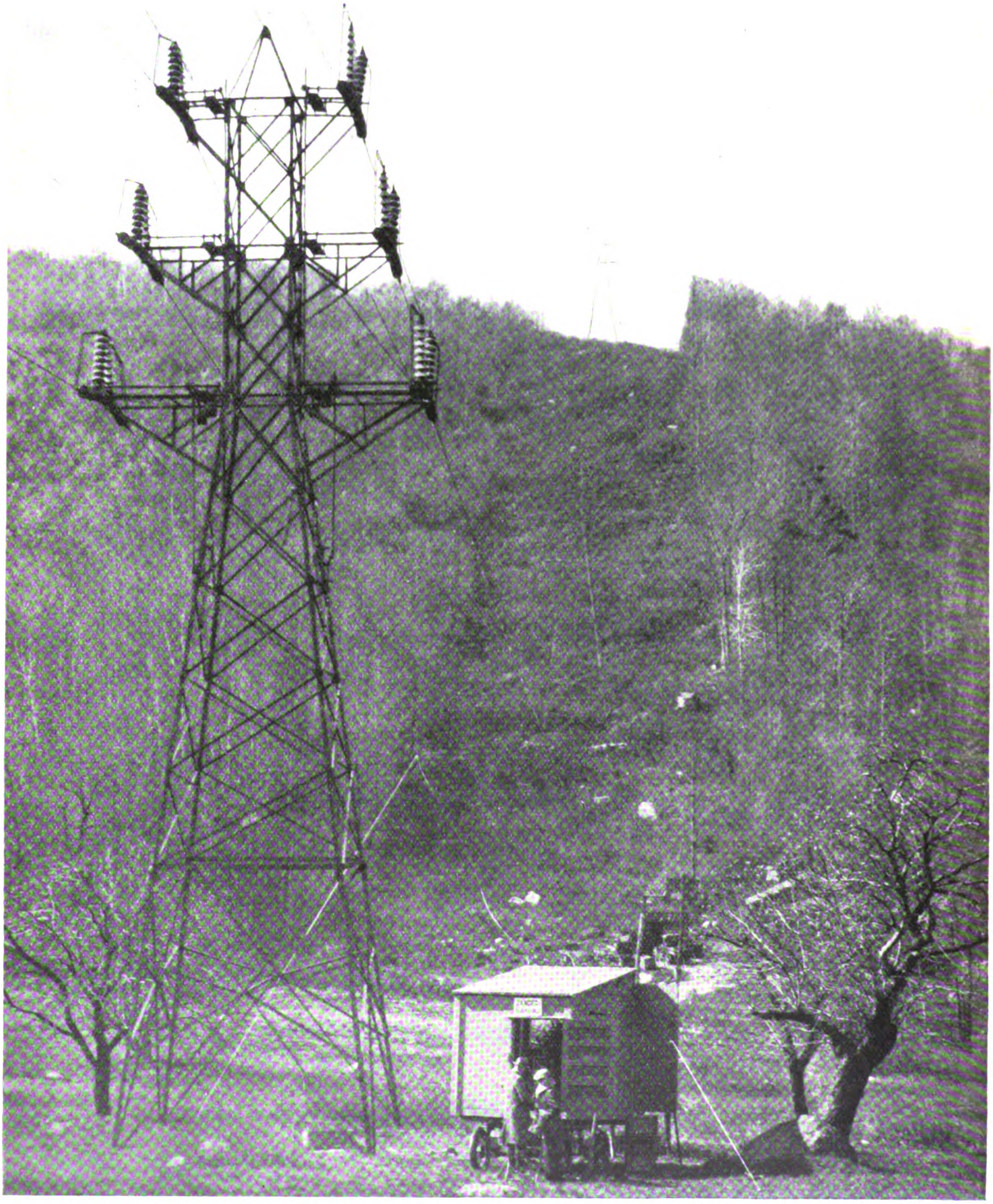

SUPPLYING LIGHTNING DISTURBANCES FOR TEST

Research Engineers no longer have to await the random moment when Dame Nature chooses to play her lightning pranks. With portable equipment, artificial disturbances can now be generated at will and released on a transmission line for studying impulse voltage phenomena by means of suitably located cathode-ray oscillographs and surge voltage recorders

GENERAL ELECTRIC REVIEW

Vol. 32 **February, 1929** **No. 2**

PROSPERITY AND RESEARCH

An article appearing in the Financial Section of the *New York Times*, Sunday, January 6, 1929, appealed to us so strongly as being a good companion to Mr. L. A. Hawkins' contribution to our present issue entitled, "Engineering Development and Research," that we reprint the following extract from it.

"The 'miracle' of American prosperity, the big volume of luxuries, comforts and necessities that we produce and consume, has been due largely to research; to an application of the same scientific methods in the conduct of business as have been so successful in medicine, biology, physics and astronomy," Edward A. Filene, president of William Filene's Sons Company of Boston, said recently before the sixty-ninth convocation of the University of the State of New York, at Albany.

"The most successful business men are those who plan and organize their operations intelligently," he continued, "like scientists, with consideration of all factors affecting them. They base their decisions on facts, not opinions. There is little place today for those who work by haphazard systems, by guesswork, by rule-of-thumb methods or worn-out traditions.

"The day of the old-fashioned business man has passed. In the pioneer stage, from which we are just emerging, quickness of decision and action, although based usually on nothing more substantial than opinions and hunches, were essential to business success. Courage, initiative, and resourcefulness completed the equipment of the old business leaders. The pioneer had to resort to snap judgment because he had little time and few facilities for searching out and weighing facts on which a surer decision could be based.

"Surely these were admirable qualities—courage, initiative and resourcefulness—but they are not qualities that will alone meet the requirements of modern business. Today those concerns that are scientifically organized and conducted intelligently are succeeding; the others are failing. Policies founded on research are conquering. As a business man, I am convinced that research is one of the most important factors in successful management.

"Those who undertake to operate on the basis of personal opinions," Mr. Filene continued, "unsupported by facts, cannot hope to survive the coming periods of super-competition against well-organized firms with large research establishments. Even now banks and investment brokers look to the research activities of a firm as a gauge of its strength.

"It is generally understood that a major factor in the growth of the General Electric Company was the wise, basic policy of research. The General Electric Company literally grew from a small laboratory to the mammoth corporation it is today. American business is spending, according to some estimates, more than $200,000,000 a year on research, $70,000,000 .through the government and $130,000,000 through commercial firms.

"Larger corporations, such as the General Electric Company, the United States Steel Corporation, General Motors, United States Rubber Company, Western Electric Company and the American Telephone and Telegraph Company, spend millions of dollars a year and employ thousands of scientists, engineers, statisticians and analysts in research work —not only in the study of production but also of distribution problems.

"The American Telephone and Telegraph Company spends $15,000,000 a year on the Bell Laboratories, which occupy three floors of a big building in New York and employ 4000 persons. General Motors has erected an eleven-story building in Detroit, covering 25,000 square feet of ground, to house its laboratories and staff. Modern business does not rest on its oars.

"Mr. Young's company has a research staff that has been called 'the most notable group of industrial researchers in the world.' This distinguished organization of chemists, physicists and engineers has had the services of such men as Steinmetz, Langmuir, Coolidge and Whitney. To quote one admirer 'They have chained lightning, and heard the clash of atoms they could not see, in thunderous tones.'

"It may not seem important to the general public to chain lightning, or hear the crash of atoms, but the discoveries the General Electric research staff has made in pure science have saved the world literally billions of dollars.

"Langmuir's discovery of the gas-filled electric globe has resulted in a saving of millions of dollars a year in electric current alone, it has been estimated. The General Electric Company's development of the vacuum tube has made possible the development of radio, and the great industry it gave birth to. That is but part of its contribution.

"We have entered on an age of applied science," the merchant said. "The race between science and 'get thereness' has been a tortoise and hare race, and the tortoise is far ahead while the hare lies dying from overleaping itself. The 'go-getter,' with his rule-of-thumb methods, is looking for a job, while the college-bred professional, trained to apply facts to business, is coming into his own, and blazing a new path to success, a straight road of straight thinking.

"Mass production and mass distribution, the fruits of research, will give us great material prosperity, but the by-products of this new scientific era are the most important. For one thing, business depressions and crises will be made more and more unlikely. Leading business men, bankers and statesmen the world over now recognize that these depressions, resulting in irregular employment and great unemployment, are not inevitable but are due to bad business thinking and bad financial thinking. By straight thinking—scientific thinking based on scientific research—they can be largely prevented."

Engineering Development and Research

By L. A. HAWKINS
Executive Engineer, Research Laboratory, General Electric Company

ENGINEERING development and research are and should be closely associated in practice but they differ quite fundamentally in their nature.

Engineering development is a very ancient human activity, dating back at least to the time when primitive man constructed the first crude cart or wheelbarrow, or rigged the first sailing craft. It has always been an essential part of industry, and its nature and purpose are fully understood throughout the world of business.

Research is a much newer thing. Although Galileo developed, and Francis Bacon expounded, its principles and method some five hundred years ago, it was still unknown to American industry at the beginning of this century. Not until the outbreak of the World War, when the British fleet took its strangle hold on German commerce, did business in this country awake to the unpleasant realization of its dependence on German industrial laboratories, and, as a result of its deprivations, begin to take a serious interest in research. It is therefore only natural that there should be divergent views and some confusion regarding the nature of so new an activity.

For instance, some have assumed that research in an industrial laboratory must be of quite different a character from the scientific studies which have been conducted sporadically in our universities, and the terms "applied research" and "pure research" have frequently been used to distinguish between the two. Now these terms, although they have been used by authoritative writers, seem to represent a confusion of research itself with the results of research.

It is reasonable enough to speak of pure science and applied science, for science is knowledge, systematized knowledge, and knowledge may obviously be applied to practical affairs or it may not. But research is simply an exploration, a systematized search, and whether or not what it finds is eventually applied has nothing to do with the nature of the search itself. Suppose a new element is found, filling one of the few remaining gaps in the periodic table. It may find an immediate use, or may find none at all; but the character of the research which led to the discovery can hardly be affected by the subsequent events which determine the degree of practical utility of the discovery. "Pure research" and "applied research" are equally misnomers.

It is of course legitimate to speak of research in the field of pure science and research in the field of applied science, to distinguish between an effort to broaden knowledge of a kind not yet applied to practical affairs and a similar effort to increase our stock of scientific information of a kind already utilized industrially. For instance, an investigation of the degrees of ionization in spiral nebulæ, or of the mechanism in deep sea fishes for producing phosphorescence, is research in fields remote from the activities of man, and the chance of a practical utilization of results may seem small. On the other hand, a study of the mechanism of explosions in an internal combustion engine is dealing with a subject of immediate practical interest to all of us, and new knowledge is nearly certain to find prompt industrial application.

But even this distinction is merely one of probabilities, for new knowledge has a way of finding applications in most unlikely places. Who would have guessed that a study of the spreading of oil on water would have yielded knowledge which later was to prove of value in the development of efficient radio tubes, or that an academic study of the mechanism of the "Edison effect" in incandescent lamps would have revealed new principles which led to the modern power tube and so made possible the great new industry of radio broadcasting? So, improbable as it now seems, it is entirely within the range of possibility that the development of the truly efficient lamp of the future, or something equally important, will be guided by a hint coming to us from a fish five miles below the surface of the ocean or from a nebula ten million light years away.

But I have strayed away from the point I wished to make—that there is inherently no fundamental difference between research in an industrial laboratory and research in a college laboratory.

I believe there are common misuses of the term "research" other than coupling it with such words as "pure" and "applied." It is often stretched beyond its elastic limit to make it cover things it does not properly fit. For example, the term "research" is often used as if it were synonymous with "testing." I have seen a list of so-called "research problems" on which graduate students of a prominent engineering college were engaged, and of which few if any were what I would call research, or in my opinion were adapted to lead the students to a better understanding of the purpose and methods of research. A typical problem was to obtain the characteristics of a given transmission line. That might require many measurements and engineering calculations. It would be useful training for an electrical engineer, but it would have nothing to do with research.

Research is not the seeking of specific engineering data on existing devices or systems. It may be desirable to know to another decimal point the open-circuit voltage of a certain primary battery, but to obtain it by refinements of measurement is not research. Research differs from testing as the work of an explorer or pioneer differs from that of the surveyor who follows him. Research is not the obtaining of more accurate data regarding what is already known. It is exploring the unknown for new generic facts or principles. Testing deals with existing things for their own sake. Research seeks the new knowledge which will make new things possible. Research may involve extensive testing, but the testing is only incidental, a means to an end. If nothing but testing is involved, the work never becomes research. Just so, the explorer may utilize surveying instruments, but the use of surveying instruments is not in itself an exploration.

It follows from the foregoing that not all laboratories are research laboratories. This is true both in industry and in academies of learning. An industry may require scientific control of factory materials and processes. It may need technical purchasing specifications, and acceptance tests of raw materials; it may need metallurgists to control its foundry, its forge shop, its heat-treating processes, and chemists to control the production of paints, varnishes, insulations, and ceramic products; it may have need of the development and standardization of instruments and test methods to an extent requiring a staff of highly trained engineers and physicists; it may need a development laboratory to improve its apparatus, to develop new devices, and to find new applications for its products. Yet none of these things is research.

All these activities—testing, factory process control, standardization, and development, are the applications of existing knowledge to the problems of industry. They are bound up with, and can exist only in connection with, industry; they represent applied science, or engineering. Research on the contrary has to do with generic facts or principles; it need have no connection with industry. It is fundamentally the same whether conducted at a university or in an industrial laboratory. It is essentially pure science until engineering steps in to apply it.

Organizations for research in college and in industry are, however, ordinarily quite different; and it is with research in industry that this article is intended to deal. I shall consider primarily the most common form of industrial laboratory, that which is operated by a single industrial corporation for its own benefit, and shall not attempt to discuss the special problems of the co-operative laboratory, several of which have been fostered by the National Research Council and supported jointly by a number of companies in the same industry, nor of the consulting laboratory such as that of Arthur D. Little, Inc., of Boston, or the Electrical Testing Laboratories of New York.

All who have given thought to the subject have recognized not only the desirability but the practical necessity of research in American industry if it is to hold its place in international competition. Germany, the nation which first taught the world the possibilities of the industrial laboratory, and which owed its pre-war commercial successes largely to applied science, has now turned eagerly to the fountain head of its past prosperity and is striving with renewed zeal, and already with striking success, to derive from research the means of retrieving its fallen state. Other nations have learned from the war the economic importance of industrial research and have organized to pursue it. America surely must not lag behind.

And never were the possible rewards of industrial research greater than they are today. Scientific discovery and theory are advancing far faster than ever before and the pace is steadily accelerating. Physical theory has so far outstripped not only the applications but the concepts of physical science that it is as yet scarcely capable of expression except in mathematical terms. It is unbelievable that the new worlds opening to view by this rapid and vast extension of the horizons of science will not yield in time rich materials for new industrial development, and the largest share in those riches should fall to those industries which, through research, participate in the scientific advance, and maintain close contact with all the advancing units in their sector.

Engineering development and research have the same ultimate objective—the enlargement of sales by the improvement, cheapening, diversification, or extension of application, of product; but whereas engineering development seeks advantage through the best utilization of existing knowledge, just as a factory seeks advantage through the best utilization of available raw materials, research seeks new knowledge for future utilization as an industry might prospect for sources of better materials. Or as a tire manufacturer may start new plantations of rubber trees to insure a supply of rubber for the future expansion of his business, so an industry may start a research laboratory to insure a supply of scientific knowledge for the future expansion of its engineering development.

To the industry contemplating research work, three problems immediately present themselves—the type of research which should be undertaken, the relation the research staff should bear to the rest of the organization, and the matter of personnel. These problems are not wholly independent, for each is modified by the solution arrived at for each of the others, but they may profitably serve as the three main heads for our discussion.

The type of research which a given industry may profitably undertake may depend on many factors, such as raw material supply, market conditions, competition, or patent situation, but foremost of these is the nature of its product or products. In general there are two types of research which we may distinguish by the terms of "intensive" and "extensive." By "intensive research" we mean investigations which are confined to a definite field and have the immediate object of improving, cheapening, or extending the applications of, process or product in that field. By "extensive research" we mean investigations of fundamentals, with no immediate practical objective, but with the expectation of broadening the scientific knowledge on which the industry is based, with the faith that ultimate applications will be found which will justify the expense of the research.

Examples of the two types of research may be drawn from the developments in incandescent lamps. The first tungsten filaments were made by mixing tungsten powder with a binder to form a paste, squirting the paste through a die, and then baking the filament to carbonize and drive out the binder. The result was a pure but very fragile tungsten filament, which required delicate and costly manipulation for its mounting, and which yielded a lamp much more efficient but much more costly and fragile than the carbon lamp. It was obvious that the desirable way to form a tungsten filament was to get it into wire form and draw it to size. But the problem was how to do it, for tungsten was a most brittle metal and had resisted all attempts to work it mechanically. This problem was made the subject of a long and costly research in the course of which many new facts in the metallurgy of tungsten were laboriously unearthed. When finally success was achieved, it was the attainment of the goal which from the beginning had been before the eyes of the workers. Here was an excellent example of what we mean by intensive research.

Now when tungsten first became industrially important through its use as a lamp filament, little was known of its physical characteristics. Among the points of scientific interest was its vapor pressure. This was carefully investigated over a wide range of temperature, on filaments in vacuum and filaments in inert gases. This work was undertaken with no clear conception of any practical application of the data, no expectation of an immediate improvement in tungsten filament lamps, but simply to extend the scientific information on a material which had become important to the industry. But about the same time another problem arose in connection with a heating device, which led to a study and revision of the formula for the loss of heat from small wires in air. The revised formula, combined with the data on vapor pressure of tungsten in inert gases, gave the clue to an entirely new type of incandescent lamp—the gas-filled or Mazda C lamp. The investigation of the vapor pressure of tungsten was a good example of what we mean by extensive research, and of the way in which such research may lead to practical developments of great commercial value.

The commercial value of the improvement in incandescent lighting resulting from these two developments, drawn tungsten and the gas-filled lamp, would be hard to evaluate. The profits accruing to the General Electric Company might be estimated approximately, but the far greater returns the public has received are incalculable. It could easily be shown that if the public were to use the same amount of artificial light that is used today but had only carbon filament lamps to produce it with, it would increase the nation's lighting bill by more than a billion and a half dollars a year. Of course such an expenditure could not be afforded. We would get along with less light. How much that would cost us in efficiency in the factory, comfort and beauty in the home, and safety on the street, can only be guessed. The modern automobile lamp and the flash light, flood lighting and the amateur motion picture projector would all be non-existent.

Whatever profit a corporation may make from any successful research, the public always gains far more. The purchasing public profits directly, while the whole nation's business profits indirectly by the strengthening of the position of American industry in international competition, for each new technical development gives a competitive advantage to the country of its origin.

Indeed there are many fields where research should be immensely profitable for the public, but where no industrial corporation could look for a return which would justify to its stockholders the expense of research. Some private foundations, like the Rockefeller Institute for medical research, have done excellent work, but we should not be forced to rely on the occasional gifts of wealthy men. The Bureau of Standards, and other government bureaus, both federal and state, in the fields of agriculture, mining, forestry, etc., have done work of much value, which should be greatly extended, but which must probably await the better education of the public to the need for research, before it can begin to grow as it should. Meanwhile the National Research Council is doing what it can to foster research by coöperative industrial laboratories and by college laboratories.

It is the probability or the possibility that new knowledge of fundamentals may lead to new and valuable practical developments which justifies an industrial laboratory in embarking on extensive research, for the one significant difference between the industrial and the academic laboratory is that the former must in the long run justify its existence by financial returns.

Now just as the fruits of exploration of an unknown country could never be foretold, so the practical results, if any, of a given line of extensive research can never be foreseen. That the consequences of a study of a phenomenon in incandescent lamps should revolutionize the x-ray art and create the new art of broadcasting was surely unpredictable. Equally so was the fact that the same series of experiments which led to the Mazda C lamp should lead in time to a wholly new method of electric welding.

During the experiments which led to the gas-filled lamp, tungsten filaments were operated through a wide temperature range in various inert gases, and the watts lost measured. When watts were plotted against temperature, a smooth curve was obtained for all gases but hydrogen. Here, at a critical temperature, there was a sharp break and the watts rose abruptly. It was guessed that this phenomenon was caused by dissociation into atomic form of the hydrogen in contact with the hot filament, the heat of dissociation being thus abstracted from the filament. This was proved to be the case by the intense reducing effect of the atomic hydrogen. This discovery lay fallow for many years, until in a college laboratory another experiment was made with results the author could not explain. From the knowledge gained by our early work, we saw that the experimental results were undoubtedly produced by the dissociation of hydrogen, but the interesting thing for us in the latter experiment was that it showed that the hydrogen persisted in atomic form for some little time, instead of immediately recombining as we had before supposed. This phenomenon has now been utilized in a practical way. A torch was built in which hydrogen was blown between tungsten electrodes. When an arc was drawn between the electrodes there was produced an intensely hot flame of atomic hydrogen. When this flame was directed against a metal surface, the hydrogen atoms recombined, giving up their heat of dissociation to the metal. We thus had a new type of flame for welding, which was much hotter than the oxy-acetylene flame, which excluded air from the hot metal so as to avoid the formation of the oxides and nitrides which tend to make ordinary welds brittle, and which had so powerful a reducing action that perfect welds could be made with metals like aluminum or high chrome steel which always carry a film of oxide which defies the ordinary welding technique. If the skyscraper or steel ship of the future is fabricated by atomic hydrogen, we shall have to admit that they are strange things to have come from a lamp bulb, and that the marvel of Aladdin's lamp has been surpassed.

Since the ultimate applications of extensive research are so impossible to foresee, it follows that the probability that a given industry will derive direct financial returns from a given line of extensive research is directly proportional to the field that industry covers, that is to the variety of its products and of their applications. A new fact in chemistry has a good chance of finding an application somewhere among the multifarious products of the Du Pont Company. Almost any new fact in physics is likely to prove useful in some product, or the application of some product, of the General Electric Company. Those companies can justify extensive researches of a kind that would be economically unsound for an industry with a single product, even though its applications were as far-reaching and its business as great as that of U. S. Steel or Standard Oil.

Industries with a limited variety of products will therefore ordinarily confine themselves to intensive research. The investigations will all center definitely on that product, so that the laboratory conducting them will be of what Dr. Mees aptly calls the "convergent" type. (1) In such laboratories, as Dr. Mees says, the investigations may cover a wide range of science, but they are all directed toward the elucidation of associated problems related to one subject.

No laboratory of the convergent type has been more successful than that directed by Dr. Mees. The following quotation from his writings therefore carries the highest authority.

"In a convergent laboratory there is always a temptation to stray from the field covered by the laboratory. The men working in such a laboratory will often be intensely interested in the whole of the science with which they are associated, and will have original ideas of considerable value which they will naturally wish to test experimentally but which have no direct relation to the general work of the laboratory. As a rule, it is necessary to resist this tendency, and if a man is very anxious to undertake work which cannot be seen to have any relation to the work of the laboratory, he should be advised to obtain a position in a laboratory where his work will be in keeping with other work done in the place. It is necessary, however, to be very cautious in deciding on this ground that any piece of work should not be done and, especially, problems should not be rejected on the ground that they are too theoretical, provided that the theory is of direct importance in connection with the main lines of work carried on in the laboratory. As a general rule, it is better to err on the side of too much theoretical work than to run the risk of doing superficial work and missing the main points which would have given really valuable results."

The decision whether a proposed laboratory is largely to undertake extensive research or is to confine itself for the most part to intensive investigations, or, as Dr. Mees expresses it, whether it is to be of the divergent or convergent type, is an important factor in the problem of the relation of the research staff to the other departments of the company. In general, two schemes are in successful operation. In one plan, research and engineering are in effect consolidated under a single head, with the title of chief engineer or director of research, and with responsibility both for research and for engineering development and design, and often for control, in part at least, of factory process. In the second scheme, the research laboratory is independent of engineering and factory departments, and its director's duties in regard to them are of an advisory character.

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(1) C. E. K. Mees: "Organization of Industrial Scientific Research," McGraw-Hill Book Co.

Each scheme has its advantages. Direct control by the research head of engineering and of factory process insures the most immediate and effective utilization of the research findings in engineering development and in production. When the number of products is not great, so that the research is mostly intensive and the laboratory of the convergent type, it is usually possible so to direct the research work as to cover continuously all the product, and so to organize the staff as to provide for all requisite engineering development and supervision. In that case a separate engineering department is superfluous and the consolidation of research and engineering responsibility would seem to be the more efficient arrangement.

The second scheme, of making the research laboratory an independent department, without direct responsibility for engineering and manufacture, has the advantages of enabling its director to take a more detached view and sometimes to gain a better perspective of the company's major problems, and to some extent of freeing the research staff from the constant pressure of commercial considerations and the research facilities from the encroachment of production requirements, which in any well-ordered business must take precedence over experimental needs.

When the variety of products is great, so that considerable extensive research is justified, and so that to cover all products continuously by intensive research would require a staff of unwieldy size, it would seem that it is the better plan to make the research laboratory independent of the engineering department.

The lines of extensive research which a company undertakes may for long periods have little in common with any of the engineering activities, so that nothing is gained and much is lost by bringing them into one department and thereby placing their needs to some extent in competition. An independent laboratory has greater mobility. Since it is not tied down to steady responsibilities it can shift its attention and concentrate its energies on successive problems as emergencies arise. It is ready at all times to help to the limit of its ability where help is most needed, and that is the chief duty of any industrial laboratory, for no matter how much extensive research it may conduct, it should always consider itself primarily a service department and should give to the urgent needs of engineering or production precedence over its own scientific work however absorbing and important it may be.

Thus it would seem that in general we should have two types of industrial research organizations—one, adapted to the corporation, large or small, with limited number of products, which devotes itself to intensive research and in which research and engineering are consolidated; the other, adapted to the large corporation with great variety of products, which carries on considerable extensive research, independent of engineering and factory.

The first type requires a very definite and relatively fixed organization plan which positively allocates the responsibility for each activity. The second permits a much looser or less formal departmental structure, since its functions are mostly advisory rather than executive. This difference is a factor to be considered in the matter of personnel, but before coming to that most important and most difficult problem, let us consider some of the points common to all research laboratories of whatever type.

A research laboratory, if it is to prosper, must be an organic growth. Probably no man living could organize a large new laboratory and make a success of it. Such an institution would be sick from the beginning, for when a research director must spend his time in seeking problems for his staff, his laboratory is in an unhealthy state. The problem should be seeking the man. Only when the number of problems is greater than the staff can handle, so that the selection of the more urgent is the director's constant task, is a laboratory on a safe footing. Growth should be the result of pressure from without, not of ambition within the laboratory.

In another sense the laboratory should be an organic growth. Each part should contribute to the well-being and efficient functioning of every other part. The spirit of the laboratory should be the spirit of teamwork. In some of the early German laboratories, secrecy and what might be termed the "compartmental plan" prevailed. Each man worked behind locked doors and only the director knew what each was doing. Such a system forfeits the greatest advantage an organization should have over an individual worker, the cumulative factor of teamwork. If each man's work is made helpful, and his knowledge freely available, to all the others, the total output should rise not in arithmetical proportion to the number of workers but in some geometrical ratio.

In the work of a laboratory, as in every other organized human activity, the foremost factor in success is leadership. Fortunate indeed is that laboratory whose director possesses, in addition to the requisite technical knowledge and business judgment, an infectious optimism and devotion to scientific truth, to induce a like enthusiasm in his co-workers, and an understanding perception of their individual problems and generous recognition of their accomplishments to inspire in them an affectionate confidence in their leader. In such a laboratory the growth is inevitable of an *esprit de corps* which will enforce success when success is at all possible.

No plan or system can compensate for the lack of such leadership, but there are other things that can help and things that can hinder the growth of the spirit of teamwork. Everything is helpful that serves to accentuate the community of interest of the whole staff, to foster a free interchange of ideas, or to subordinate selfish individual interests. Frequent group meetings of those working on similar or related problems are desirable to report progress, and to elicit discussion and suggestions. Informal consultations should be encouraged, and each man taught that when his work leads him on to unfamiliar ground, better known to some other member of the staff, he should promptly seek the other's advice or help. Thus all the special knowledge available in the laboratory is brought to bear on each problem, and thoroughgoing team play is achieved.

Bonuses for inventions, or other conspicuous recognitions of individual achievement, are fatal errors, conducive to secretiveness and jealousy and immediately destructive to teamwork. I have known of one organization practically disrupted in this manner, and transformed into a collection of individual inventors each working for his own selfish interest. Unfortunately our patent law requires that the patent application be filed in the name of an individual or individuals. Practically, in a laboratory enjoying true co-operation in its staff, nearly every important development represents the effective contribution of many workers, and although under the law the inventive act may be technically that of one individual, it is the co-operative actuality rather than the patent technicality which the laboratory management should stress.

Bonuses for inventions, besides being pernicious in their effects, are inherently unfair. Researches or developments of equal importance and requiring equal abilities for their successful conduct may be very unequal in the opportunities they offer for invention. Work in any new field is practically certain to result in many patentable inventions, while in a field which has been intensively cultivated for decades, the chance of invention is small. Were pay proportional to invention, no laboratory staff could be blamed, if like the men of Athens, they were forever seeking the new thing and neglecting those older fields in which lay the major interests of the company they served.

Meritorius work should be recognized in salary alone, or, if a company's policy includes a profit-sharing bonus, the share of the laboratory workers should be largely based on the contributions of the whole department to the company's welfare, and the relative amounts of the individual payments should not be permitted materially to distort the salary scale.

Whether the laboratory organization be formal or informal, it will naturally be based on the group system, with each group built around and directed by one of the abler and more experienced men. The best size for each group will depend on the characteristics of its leader. Some of the ablest research men have single-track minds and are at their best when they can concentrate exclusively on a single problem. Such a man can advantageously direct only as many assistants as can be effectively utilized on the problem at hand, and often for such a man the most useful assistant is of the adaptable or receptive type rather than one possessing great originality and aggressiveness. Only rarely is to be found a research man with mentality sufficiently detached and versatile to be able to direct and contribute effectively to a number of simultaneous researches, while still carrying on efficiently his individual research work. Such a man can successfully supervise a large group or several groups, and the more originality his assistants possess the better. But in general it should be remembered that, just as many a good workman has been spoiled to make a poor foreman, so an excellent research man may be spoiled in making a poor director.

In the choice of problems the director of the laboratory should have full authority, for his is the responsibility for the laboratory's success, and the wise choice of problems is one of the two controlling factors in that success, the other being the ability with which the chosen problems are attacked. But the director of a large laboratory is to be pitied if he has not among the heads of the research groups some at least whom he can largely trust to select wisely the problems in their special fields.

To assist him in selecting wisely, the director should obviously have full information of his company's plans and outstanding needs, commercial, technical and manufacturing. Whatever the relations of the laboratory to other departments, adequate channels for such information should be provided. The arrangement of those channels will vary so widely with differences in corporate organizations that it would be futile to try to discuss them in detail. Whatever the laboratory's place in the company's organization, the director, if not himself an officer, should report directly to a responsible officer of the company. This is to insure to the director a close contact with company policies and a clear understanding by the management of his aims and methods.

It is not to be expected that research will yield immediate financial returns. Some investigations have been continued for years and have cost hundreds of thousands of dollars before ultimate success was reached and liquidation of the expense through profits begun. Neither is it to be expected that every research will prove profitable. Probably every research laboratory must admit that the failures outnumber the successes. In most investigations it becomes necessary in time to decide to abandon them. Knowing when to stop is next in importance to knowing when to start. Many a laboratory has had experience with a line of research work which continued so long, with constant promise of success but without ever reaching it, that the wisdom of its discontinuance became a perennial question. Perhaps the best criterion is to forget the past labor and expenditure and to ask one's self whether, with one's present knowledge, the problem looks so promising that one would initiate its investigation were work on it not already in progress. If the answer is "No," then the work should be promptly discontinued, for in research, as in other ventures, it is folly to throw good money after bad.

It is the successful researches which must pay for the failures, and in general this is possible only through the patent protection obtainable on new developments. Were it not for the patent system, the industrial research laboratory would be non-existent, for no corporation however wealthy could afford the great expense of research, if its results, as soon as they were commercially developed, could be copied by competitors at the bare cost of reproduction. It is chiefly in order that a corporation may be protected in the enjoyment of the fruits of the research for which it pays, that adequate laboratory records are essential. This is too little realized by many laboratory workers, who often think of reports as merely objects of technical reference in the future and conclude, rightly enough were this their only utility, that since the same problem rarely comes up twice in quite the same form, so that the work would need to be repeated anyway, the value of reports is not enough to pay for the time of writing them. They do not realize that a patent interference, determining the rights to an important invention, may be won or lost on the adequacy of laboratory records. A research man who fails to make such records of his work is as faithless to his employer as a hired mining prospector would be if he became so interested in his valuable discoveries that he omitted to stake out his claim.

Laboratory records should include both original data and reports. Original observations should be entered daily in a notebook or log, duly dated and witnessed. This is the primary record. But that record may usually be clarified and strengthened by periodic reports summarizing the progress of the work.

While the preparation of reports is irksome to most research men, so that obtaining adequate reports is an acute problem in many laboratories, the privilege of writing papers for presentation before scientific and technical societies is usually eagerly sought. Such publication should be actively encouraged by the laboratory management. At times commercial or patent considerations dictate a delay in publication, but subject to such reasonable postponements the laboratory should insist on a corporate policy of free publication of laboratory results. Nothing less is fair to the research workers. They should receive great good from contact with their fellow members in the technical societies, but they cannot expect to receive without giving, and their standing with their fellows is measured by the worth of their contributions. In consequence no laboratory deserves or should expect to retain the best men if it does not make it possible for them to receive, through publication of their work, the recognition in scientific or technical circles that is their due.

Another obligation a laboratory owes its workers is the provision of adequate facilities, and foremost of those facilities is a good library. It is the most essential tool, and one that the best men use the most.

Geographically, a laboratory should be located as close as possible to the factory or factories it serves. Proximity promotes understanding by the laboratory of factory problems, invites recourse to the laboratory by the factory superintendents for help in their troubles, facilitates the investigation by the laboratory of factory process, and renders the factory facilities conveniently available for the making of apparatus for laboratory use and for trying out laboratory findings on a semi-productive scale.

But as far as possible the laboratory should be self-contained in its mechanical equipment. It should have its own tools for producing such special models or experimental apparatus as it frequently requires. Usually when such apparatus is needed some investigation is awaiting its completion, and if it must take its turn in a manufacturing department, yielding precedence to production on customer's requisition, the laboratory work suffers uneconomic delays which may throw its whole program out of gear. The laboratory should therefore in its operations, be, as far as possible, a self-supporting unit.

Financially, also, the laboratory should be self-supporting as far as accounting can make it so. I mean by this that the laboratory expenditures should as far as possible be assessed against the cost of the specific apparatus that benefits from the work, and liquidated in factory cost of that apparatus, rather than carried as an overhead expense. For instance, suppose that, as the result of a laboratory development, the cost of producing a certain line of apparatus is reduced ten per cent. If the cost of the laboratory work is not charged against that apparatus, then the reduction in factory cost will probably be quickly followed by a corresponding reduction in selling price, so that the customer gets all the benefit, while the manufacturer's profits are reduced by the cost of the laboratory work. If, on the other hand, the laboratory expense is treated as a direct development charge against the apparatus, the factory cost will not be immediately lowered by the full ten per cent but will be maintained at perhaps 95 per cent until the laboratory expense is liquidated.

Such direct allocation of laboratory charges is helpful to the director as a continuous check on the economic justification of each line of work. If the department receiving the charges accepts them cheerfully, it is the best kind of assurance that the expense of that investigation is well justified.

Every laboratory should of course operate on the budget system, but too much itemization of the research work should not be required. In engineering development the cost of each line of expenditure can be fairly accurately forecast, for the end is in view from the beginning, and a quite thoroughly itemized budget can be prepared. In research this is not so, for the initial exploration may reveal far greater possibilities, warranting a much greater expansion of the work than could possibly have been foreseen, or it may prove disappointing and lead to a total cessation of the investigation in its early stages. The total research budget may be fairly accurately estimated, but extensive itemization is mere guesswork and a waste of time.

The methods of insuring the prompt introduction of laboratory results into factory process or product will vary with the position of the laboratory in the organization plan and with the nature of its results. When the director of research is also chief engineer, the matter is simple. Laboratory findings may immediately be translated into technical instructions binding on the factory. Where the laboratory is an independent advisory department, salesmanship is often necessary, particularly when something radically new in process or product is involved. At such times it may be necessary for a laboratory not only to carry to completion the engineering development of its research results but even to manufacture for a time in small quantity to demonstrate the merits of its product. That manufacturing may be carried on within the laboratory itself, if the necessary facilities can be provided economically, or the laboratory may temporarily take charge of a section of a factory department. Our laboratory has often resorted to each of these measures. At times a new and permanent factory department has been created with a laboratory man at its head.

I have left to the last the discussion of the most difficult and also the most important of an industrial laboratory's problems—the selection of the personnel. I have already said that the foremost factor in the success of a laboratory is its director. Next to him in importance, far outweighing organization plans, facilities, or accounting methods, is the quality of the research staff. First-class research men are much rarer than first-class engineers. Research and engineering require different aptitudes for success.

In our experiences we have seldom found in one man special aptitude for both engineering and research. The mental attitude required is wholly different. The successful engineer is the type that likes to deal with certainties. He likes to utilize materials whose properties he knows and has confidence in, and to produce therefrom concrete results in the way of new structures, new devices. He likes to see the tangible result of his labors. The research man is primarily interested in the unknown. He seldom has the patience to carry a new idea through to a finished design. He differs from the engineer as the explorer differs from those who follow him to develop what he has found. The ceaseless urge toward the unknown which marks the research man is well expressed in Kipling's poem "The Explorer"—

> Till a voice, as bad as conscience, rang interminable changes
> On one everlasting whisper, day and night repeated: so —
> "Something hidden. Go and find it. Go and look behind the ranges,
> "Something lost behind the ranges. Lost and waiting for you. Go!"

It is this restlessness in the fact of the unknown, which Kipling elsewhere characterizes as "insatiable curiosity," that drives the research man to continual experiment. If an engineer is temperamentally inclined to experimentation, he cannot too often "obey that impulse" without jeopardizing the conservatism of his designs.

Again, the research man needs the habit of questioning everything, of seeing the unknown in the familiar. Herbert Spencer in his autobiography attributed whatever eminence he attained in philosophy to the inculcation in him as a boy, by his father, of the practice of taking nothing for granted but of seeking the why and how of everything. The same habit is needed for successful research. Just as, to the poet, the "primrose by the river's brim" was something more, so to the research man the commonplace phenomenon must shout its question. Newton's falling apple and Watt's dancing kettle lid may be apocryphal, but they are none the less veridical. They typify the significance of the commonplace to the mind having natural aptitude for research.

The engineer, for economic reasons, must be a devotee of standardization. His interest in the exceptional is in bringing it into conformity with standards. To the research man the exceptional is an inspiration and a guiding light. He is ever on the lookout for it, and when he finds it he seeks to develop its peculiarities to the fullest extent. It was by observing the slight difference in weight between atmospheric and chemically prepared nitrogen that Lord Rayleigh was led to the discovery of argon. It was said of Charles Darwin that he possessed to an exceptional degree "the power of never letting exceptions pass unnoticed."

In the relative importance of optimism and balanced judgment, research and engineering are far apart. There is no vocation in which optimism is more essential than in research. It is easy to think of many reasons why a proposed experiment would be futile, but the man who makes the discoveries is the man who goes ahead and tries it just the same. Lord Kelvin said in 1896 that man could never fly in a heavier-than-air machine. In 1900 it was authoritatively declared that the incandescent lamp with carbon filament as perfected by Edison could never be improved. In each case the accomplished fact followed closely on the heels of the denial of its possibility. No truth in metallurgy seemed more firmly established than the utter refractoriness and unworkability of tungsten, but tungsten wire is now being drawn at speeds of two hundred feet a minute and down to a diameter of a seventh of that of a human hair. Optimism to research is what vitamins are to the animal organism.

In the engineer, optimism is of value, but it must be sternly ruled by sound judgment. He has not the safeguard of the research man, whose optimism, if excessive, is promptly and harmlessly checked by laboratory experiment. The engineer's mistakes, like the doctor's, may be disastrous to others, and since, unlike the doctor, he cannot bury them, they are disastrous to the engineer himself.

Imagination, but of different types, is an important asset to both research man and engineer. The research man's imagination should be of the philosophical type, to enable him to coördinate his observations into hypotheses for experimental verification or disproof. The engineer, too, should be able "to see things," but the pictures his imagination is called upon to draw are usually of the tangible, mental presentations of the devices he is to design. The imagination that depicts a new design of locomotive or airplane has a technique different from that used in dealing with the quantum of Planck, the atom of Bohr or the wave mechanics of Schroedinger.

Of course there are many characteristics which should be possessed by both the research man and the engineer, but these are mostly characteristics essential in any profession, such as intellectual honesty, clear thinking, industry, resourcefulness, perseverance, etc. What I have tried to do is to bring out those features which distinguish the true research man from the successful engineer. Now suppose we should list them and ask anyone who was ignorant of the nature of our discussion what vocation would require such aptitudes. The list is: an intellectual restlessness; the ability to see wonders in the commonplace; quick perception of, and interest in, the exceptional; a high optimism; and a philosophic imagination. Might not a probable answer be that we were listing the attributes of a poet? And does this mean that great research men, like great poets, are born, not made? Is a Faraday as impossible to produce by education as a Shakespeare, a J. J. Thomson as a Robert Browning? I do not know. I know only that, just as there are hundreds capable of writing acceptable magazine verse to one who is capable of great poetry, so there are hundreds who can do useful laboratory work to one who can blaze the trail into a broad new land of knowledge. I know that there is a great oversupply of men who wish to work in laboratories, and a great dearth of truly capable research men. How far education can redress this unbalanced state of things is not for me to attempt to say. I wish only to express the hope that the growth of research work in the colleges and universities will lead to a more general appreciation of its requirements, a quicker perception of real research ability in students, and a better opportunity to encourage and develop that ability.

For the man with real aptitude and the requisite scientific training, research is by far the most attractive field I know. The successful research man may gain no greater financial rewards than the successful members of other professions, but in his work he shares with the artist the joy of creation, with the explorer the thrill of continual new discovery, with the scholar the zest of intellectual struggle and the triumph of intellectual achievement, and with the philanthropist the satisfaction of contributing to humanity's welfare. The problem of research management is not how to hold its best research men, but how to find them in the first place.

We need more and greater research centers in our universities, centers where there are such able men and such keen scientific endeavor as to attract and inspire the ablest students. Sir William Osler, in relating how during his lifetime the center of medical research shifted from Vienna to Berlin, pointed out that this was the result of the presence at Berlin of two or three great men. He then puts these words in the mouth of "Minerva Medica," in comment on her change of habitation: "We Gods have but one motto—those that honor us we honor. . . . Where the worshippers are the most devoted, not, mark you, where they are the most numerous; where the clouds of incense rise highest, there must my chief temple be, and to it from all quarters will the faithful flock." The greatest need of American industry today is the presence of a goodly number of such temples of physics and of chemistry in American universities.

The Holland Station of the Pennsylvania-New Jersey Power System

First 1200-lb. Steam Pressure Station Designed for Variable Load Operation—Many New Features Combining Economical Operation with Low First Cost

By E. M. GILBERT

Vice President and Chief Engineer, W. S. Barstow and Company, Incorporated

THE Pennsylvania-New Jersey Power System of the General Gas and Electric Corporation, shown in Fig. 1, extends continuously about 250 miles from northern Maryland, through Pennsylvania and New Jersey, to within thirty miles of New York City and to the northern New Jersey boundary line.

In order to take care of increasing demands and insure best service over an extensive territory, the new Holland Station of 220,000-kw. ultimate capacity with an initial unit of 55,000-kw. capacity has been designed and is being constructed by W. S. Barstow and Company, Incorporated, at Holland, (N. J.) on the Delaware River. The Holland Station will be the main eastern generating station of the system. On the western end of the system, at Middletown (Pa.), is located a modern, economical station of 70,000 kw. present capacity, with an ultimate capacity of 210,000 kw., the first 35,000-kw. unit of which was put into operation during 1925. At Reading (Pa.), near the center of the system, is located a station of 70,000 kw. With these three main generating stations, several hydro stations, and ample spare capacity in several smaller steam plants, the system provides a power reservoir capable of large expansion and of supplying continuous service on greatly increased demand as well as an interchange of power with neighboring power systems.

The designers of this plant were faced with the problem of creating a generating station which would better the results obtained at Middletown which is an economical 350-lb.-pressure plant receiving coal of the same quality as that which will be used at Holland, but located in a lower freight rate zone. This led to very careful detail studies comparing 400-lb. pressure, no reheat, two and three-stage extraction, with 550-lb. reheat and 1200-lb. reheat, both with four-stage extraction. The fourth-stage extraction on 400-lb. pressure was not considered economically profitable and consequently was not used in the comparison.

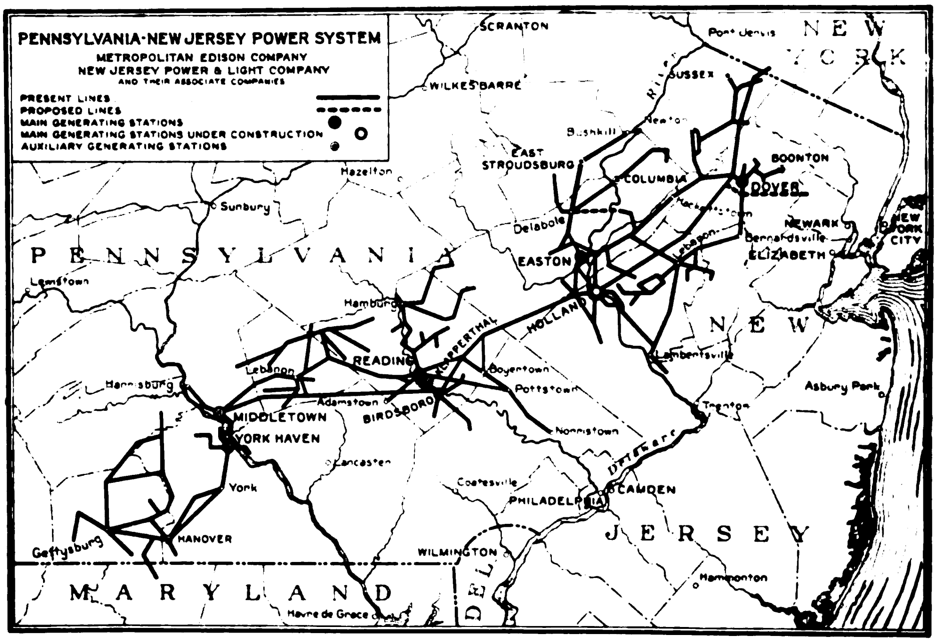

PENNSYLVANIA-NEW JERSEY POWER SYSTEM
METROPOLITAN EDISON COMPANY
NEW JERSEY POWER & LIGHT COMPANY
AND THEIR ASSOCIATE COMPANIES
PRESENT LINES
PROPOSED LINES
MAIN GENERATING STATIONS
MAIN GENERATING STATIONS UNDER CONSTRUCTION
AUXILIARY GENERATING STATIONS
SCRANTON
WILKES BARRE
Port Jervis
NEW YORK
SUSSEX
Newton
Bushkill
EAST STROUDSBURG
COLUMBIA
BOONTON
DOVER
Hackettstown
NEWARK
NEW YORK CITY
Bernardsville
ELIZABETH
Hazelton
Sunbury
PENNSYLVANIA
Lewistown
Delabole
EASTON
Hamburg
HOLLAND
CAPPERTHAL
READING
Lebanon
Boyertown
Pottstown
Lambertsville
NEW
Harrisburg
Adamstown
MIDDLETOWN
BIRDSBORO
YORK HAVEN
Norristown
Trenton
Asbury Park
Lancaster
Coatesville
PHILADELPHIA
CAMDEN
Delaware
York
HANOVER
Gettysburg
JERSEY
WILMINGTON
Hammonton
MARYLAND
DEL
Havre de Grace

Fig. 1. The Pennsylvania-New Jersey Power System

In considering the design for the station it was first necessary to determine as accurately as possible the load-factor at which the station would operate and to keep in mind that coal would cost $5.00 per ton delivered, thus allowing a greater increase in investment per cent betterment in economy than could be justified with coal costing less per B.t.u. It appears that the present tendency throughout the country toward complete interconnection of the power stations of a single system, and still further between systems of various companies, will have a decided tendency to increase the capacity-factor, making it less and less necessary to install spare units as stations are constructed, thus, of course, materially reducing the investment required, and increasing the active use of the equipment installed.

It appears also that the demand for electric power during and immediately after the late war caused greater percentage of growth than is to be expected in the near future. Also, the increase in economy between the old low-pressure small-unit plants and the present high-pressure large-unit plants was probably greater than that which can be obtained in the future in the same time interval above the plants now being designed. These new large-unit plants are taking advantage of the rapid development in economy due to higher steam pressure and superheat, reheat, steam extraction, etc., and it is doubtful if the improvement in economy for the next ten years will be as rapid as it has been in the past ten years. All things being considered, it seemed that a 50 per cent capacity-factor and 75 per cent operating-factor would most nearly represent the load conditions.

Determination of Pressure

Economy data in B.t.u. consumption, for a 50,000-kw. turbine-generator unit, were procured for the 400-lb. pressure, no reheat, and the 550 and 1200-lb. single-reheat cycles. Fig. 2 shows these data in percentages of B.t.u. consumption, with the 1200-lb. cycle used as 100 per cent for comparative purposes. These figures are based on an initial steam temperature of 750 deg. F. and exhaust to 29 in. of vacuum at all three pressures, with a reheat temperature of 750 deg. F. for the 550 and the 1200-lb. pressure, with no reheat for the 400-lb. pressure.

Detailed estimates on the first cost of the station designed for 400 lb., no reheat, two and three-stage extraction, and 550-lb. reheat and 1200-lb. reheat, four-stage extraction, were prepared, and from these estimates the fixed charges were determined. When considering the fixed charges plus the production cost it appeared that the 550-lb. pressure reheat plant was less economical than the 400-lb. pressure no reheat plant, because the saving in B.t.u. consumption of the former was more than offset by the increase in fixed charges. The 550-lb. plant was also more expensive in both first cost and B.t.u. consumption than the 1200-lb. plant. This study left but one conclusion, namely, that the station should be designed for either 400-lb. pressure or 1200-lb. pressure.

Fig. 3 indicates the conclusions drawn from careful estimates with different cost of fuel, and shows the fixed charge and fuel cost in mills per kw-hr. plotted against coal cost per ton. These curves indicate that the 400-lb. pressure, no reheat, three-stage extraction cycle, is the most economical with coal below $3.50 per ton, and that with coal above this price the 1200-lb. pressure, reheat, four-stage extraction cycle is the most economical. The 50,000-kw. turbine used in the above 550-lb. estimates was the compound unit advised by the manufacturers.

The conclusion drawn was that with coal costing $5.00 per ton delivered and a plant with 50,000-kw. turbine units, having a capacity-factor of approximately 50 per cent, the 1200-lb. reheat cycle is the most economical pressure when considering operating cost and fixed charges combined.

It should not be implied from the above that these remarks cover any criticism of others who obtain different results from those shown in our analysis. There are many conditions which might render it expedient and advisable to install intermediate pressures between 400 lb. and 1200 lb.; and a great deal of credit is certainly due to the pioneers who originally broke away from the 350 to 400-lb. pressures and began using higher pressures, such as 600 lb. Without the development work that they have done it is very improbable that we would now be considering the use of 1200-lb. pressure, and when most of the 600-lb. installations were made, 1200 lb. was in such an experimental stage, and had been used so little, that many firms would have been unwilling to build an installation requiring regular operation upon this high pressure.

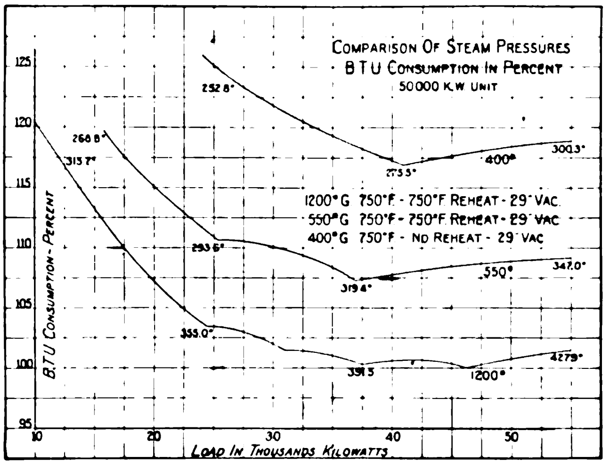


Fig. 2. Chart of B.t.u. Consumption for 50,000-kw. Unit

Again, if in our calculations a single-barreled turbine had been used for the estimates on 550-lb. pressure, this would quite materially have affected the result owing to a reduction in cost. We believe our answer is correct for our conditions, but do not wish to draw any general conclusions for application to the conditions of others.

Turbine-generator Unit

At the time the Holland Station was being designed, all 1200-lb. pressure installations in operation or considered at that date were arranged as an increment to an existing, fairly efficient station, thus allowing the high-pressure units to be operated upon base load conditions. In the case of the Holland Station, however, where a new high-pressure station was being added to a system having one relatively large and several small hydro stations, as well as interconnections with neighboring systems largely depending upon hydro stations, largely fluctuating load conditions were expected.

It was advisable, therefore, to consider with the manufacturers a design of equipment satisfactory for variable load operation; and this condition of operation was considered throughout the design of the station. The first step necessary was to get as flat a steam consumption curve on the high-pressure turbine as was possible. Consequently, it was suggested to the various turbine manufacturers that this might be obtained by the use of several steam admission valves on the high-pressure machine instead of a single valve such as that used on the 1200-lb. plants already in operation. After considerable discussion this was agreed upon; and turbines having four and five valves were designed. It appears that these machines are now being supplied to all stations of this class now being built.

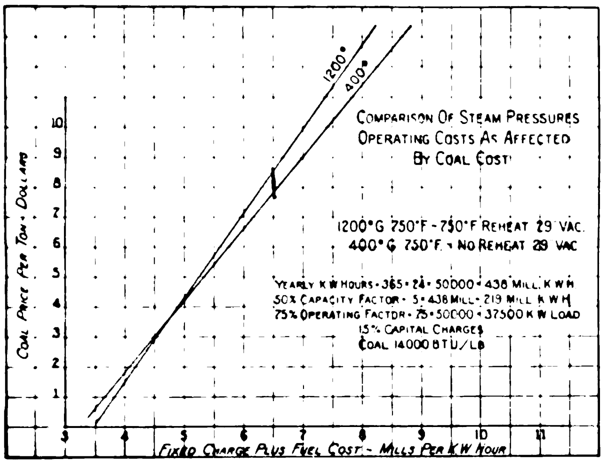


Fig. 3. Cost Analysis Based Upon Fixed Charge and Fuel Cost

Contrary to what might be expected, it was found that the first cost of the 1200-lb. turbine-generator, as now constructed, is very little more per kilowatt-capacity than the 400-lb unit, and is cheaper than the 550-lb. compound reheat unit.

Boilers

The high-pressure station calls for a very careful study of the arrangement and proportion of the heating surface making up the steam generating units in order to obtain the most economical assembly of water walls, boiler, superheater, reheater, economizer, air heater, etc. This study invariably leads toward a reduction of the high-cost steam parts as, with higher pressures, multiple-extraction plants with an increase in temperature of steam and exit gases, less of the very high-cost boiler surface and more of the less expensive economizer surface is required. Also, with higher feed-water temperature, less economizer surface and more air-heater surface can be used, the air-heater surface being the cheapest surface of all. The proportioning of these surfaces affects the first cost of the station materially.

With the use of water walls to reduce furnace maintenance, evaporators, pulverized fuel and many other features governing boiler operation, it is now possible to operate a boiler almost continuously, the outages for cleaning and maintenance covering a very small percentage of the time. This being the case, with a thoroughly interconnected system, it has been found much more economically sound to carry the load dropped during these boiler outages on other plants of the system, or to force the remaining boilers of the plant to a point above normal operation, even at a slightly increased fuel cost, than to pay fixed charges on the investment necessary for an added spare boiler. In other words, in a thoroughly interconnected system a high-pressure boiler with its large investment cost should take its place beside the turbine, when considered in relation to the economic installation of spare capacity. Consequently, in the studies for the Holland Station no spare boiler is considered for any of the pressures studied. In view of these things it seemed best to consider two boiler units per turbine, at least for the first machine, and the comparisons were made on that basis.

In practically all plants previously designed where reheat has been used, it has been the custom to build special reheat boilers which generated less steam than the other boilers in the plant, and which used most of the heat liberated in its furnace for reheating the steam not only from that boiler itself but from other boilers on the system. With a plant designed for unit operation, especially when only the first unit was being installed this method had obvious objections. If a plant could be designed with all steam generators built on the same general plan it would facilitate ease of operation and would cripple the plant considerably less if any one boiler went out of service. It would also simplify regulation of the plant; and this was an object which it was desired to obtain, if possible.

The first arrangement considered for the Holland Station consisted of a bent-tube boiler with an inter-deck convection superheater combined with one of the radiant type, and a reheater consisting of radiant type apparatus located in the side walls of the setting. This arrangement of equipment was not entirely satisfactory and the following various modifications were tried with both bent-tube and straight-tube boilers:

(*a*). Radiant type reheaters in the bridge wall of the furnace and combined convection and radiant type superheater.

(*b*). Radiant type superheaters in the furnace side walls and convection interdeck reheater.

(*c*). Radiant type superheaters in the side walls and radiant type reheaters in the bridge wall.

(*d*). Combined steam reheater and radiant type reheater together with a convection type superheater.

(*e*). Radiant type superheater in the furnace side walls with a reheater built into the last pass of the boiler.

(*f*). The same arrangement with a second stage convection reheater.

(*g*). A radiant type superheater in connection with various combinations of an auxiliary steam reheater placed in series with a convection reheater.

(*h*). The use of a separate reheat boiler.

(*i*). The use of two separate steam reheaters in series, using saturated steam at full boiler pressure and two-stage reheating.

After carefully considering all of these possible arrangements of water walls, boiler, superheater reheater, economizer, and air preheater, taking into consideration the cost of the various equipment, and after carefully balancing the cost and economies, it appeared that the best arrangement was that shown in Fig. 4. This arrangement provides for water walls, a convection-type superheater, a first-stage steam reheater and a second-stage gas reheater, economizer and air preheater, all boilers being built on similar lines.

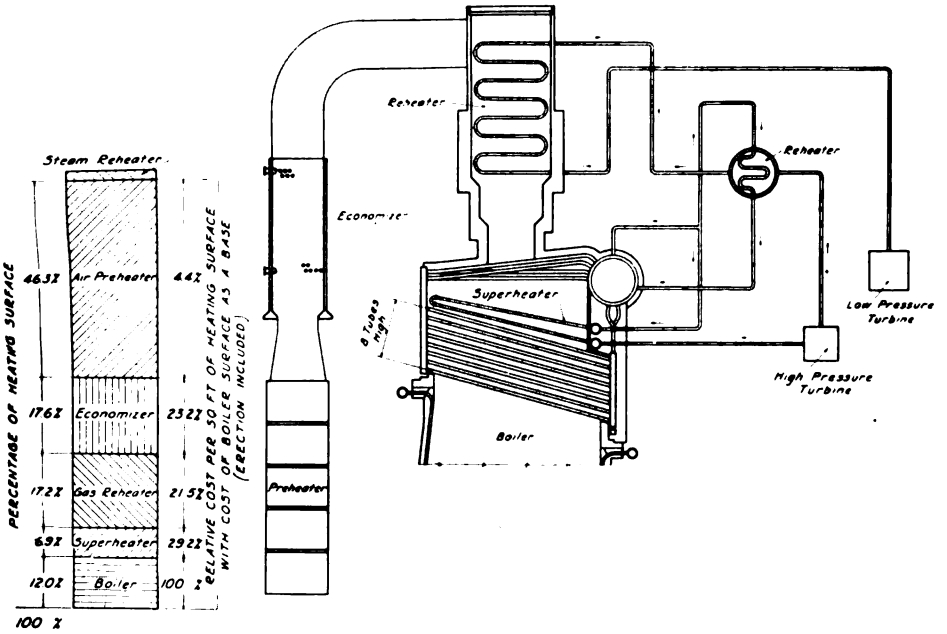


Fig. 4. Arrangement of Steam Equipment and Apportionment of Heating Surfaces

Steam from the boiler flows to the convection superheater and thence to the high-pressure section of the turbine which exhausts to the steam reheater operated in series with a flue-gas reheater and is returned to the low-pressure section of the turbine. Saturated steam from the boiler is used in the steam reheater for supplying the heat, and constant reheat temperature is obtained by thermostatic regulation of the steam to the steam reheater, the proportions of the two reheaters being so arranged that at full loads the steam reheater is nearly cut out, the flue gas reheater furnishing all the heat required.

Fig. 4 shows also the percentage of the total heating surface provided by each piece of apparatus together with the relative cost per square foot of heating surface for each, using the cost of boiler surface as a base.

Comparisons between bent-tube and straight-tube boilers inclined us towards the latter type in this case for the following reasons:

(*a*). In the high-pressure boiler the greatest expense attaches to the drums, and the straight-tube boiler with one drum had an advantage in cost.

(*b*). The straight-tube boiler allowed a more satisfactory arrangement for the gas reheater, it being difficult to place this between the first and second passes of the bent-tube boiler.

(*c*). The straight-tube boiler allows all of the high-priced boiler surface to be located in the highest-temperature zone with the reheater immediately above, and makes the most economical general arrangement of all the heating surface.

(*d*). The straight-tube boiler construction lent itself more economically to space considerations when considering the method of pulverized fuel firing that it was desired to use.

Heat Cycle

The heat cycle and arrangement of auxiliary equipment which was decided upon after carefully balancing the economies and first cost is indicated in the heat cycle diagram, Fig. 5.

The condensate after leaving the condenser is first pumped to a surge tank, with a float-valve control which may divert the condensate to an evaporated water storage tank, if necessary. The drip from the evaporator condenser is also returned to this surge tank. This condensate or feed water is delivered to the boiler through the agency of three separate pumps acting in series.

The first pump, operating against 70-lb. head, delivers the water to the deaërating heater at 273 deg. F., full load, after forcing it successively through

(*1*) the first-stage heater, taking steam from the 14th stage of the low-pressure turbine; (*2*) the small vent condenser, supplied with heat by the vents from the deaërating heater; and (*3*) the evaporator condenser, condensing steam from the evaporator and the turbine gland seals. The evaporator receives its steam from the sixth stage of the turbine.

The second feed pump operates against 600-lb. maximum pressure, and forces the water through (*1*) the third-stage heater, taking steam from the sixth turbine stage in parallel with the evaporator, and (*2*) the fourth-stage heater, which is supplied from the crossover header, receiving the exhaust from the high-pressure turbine.

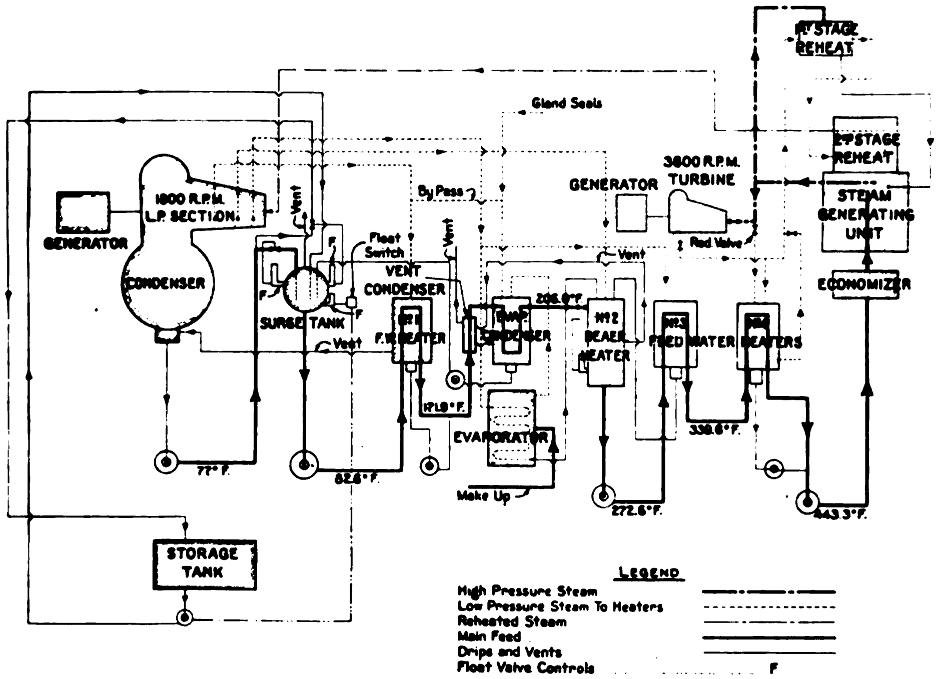

1st STAGE REHEAT
Gland Seals
2nd STAGE REHEAT
3600 R.P.M. TURBINE
GENERATOR
1800 R.P.M. L.P. SECTION.
Vent
By Pass
STEAM GENERATING UNIT
GENERATOR
Float Switch
Vent
Red Valve
Vent
CONDENSER
VENT CONDENSER
ECONOMIZER
F
206.6°F.
SURGE TANK
No 1 F.W. HEATER
EVAP. CONDENSER
No 2 DEAER. HEATER
No 3 FEED WATER HEATERS
No 4
Vent
171.9°F.
EVAPORATOR
338.6°F.
77°F.
82.6°F.
Make Up
272.6°F.
443.3°F.
STORAGE TANK
LEGEND
High Pressure Steam
Low Pressure Steam To Heaters
Reheated Steam
Main Feed
Drips and Vents
Float Valve Controls
F

Fig. 5. Arrangement of Auxiliary Equipment and Heat-cycle Diagram

The third feed pump, working against a maximum head of 1600 lb., takes the water which has now reached a temperature of 430 deg. F. at full load and discharges it to the boiler through the economizer.

The deaërator heater is supplied with steam from the tenth stage of the turbine and is equipped with float control for regulation of water supply at that point.

Fuel Pulverizing and Burning Equipment

The plant is designed primarily to use bituminous coal but so arranged that, in emergency, part anthracite could be used; and, with some small changes and additions in milling capacity, a complete anthracite burning plant is possible, if this should become advisable due to future developments in this direction or to marked change in coal supply or prices.

The bin system is being installed with mill drying, the vents from the mills being used for secondary air supply to burners. It was demonstrated that with proper speed control, for variable loads, on the direct-fired system in the present stage of development and a careful selection of the proper sized mills by both systems, there was very little, if any, difference in the total investment necessary for either bin or direct firing.

With the bin system it was possible, without extra costs, to design the plant so that all fuel could be pulverized at night during the off-peak period. This reduces labor costs, increases station load-factor, and lessens station requirements during peak-load hours. It really adds about 1000 kw. to the salable peak capacity of the plant and credit can be taken for the investment otherwise required to install this capacity. It also reduces the amount of machinery necessary to operation during peak hours and thus simplifies operation at a period of time when this is most desirable.

A further advantage in favor of the bin system was the matter of arrangement, as it was decided to make use of the opposed method of firing whereby burners would be located on two opposite sides of the furnace.

Furnace

The furnace is designed for a heat liberation of about 18,000 B.t.u. per cu. ft. at 250,000 lb. of steam per hour. The side walls are of the fin-tube type, but the two walls equipped with burners consist of bare tubes set in the brickwork.

Opposed firing allows for a much better arrangement of burners in respect to the side walls where direct impingement is undesirable, and increases the flexibility of operation. It gives great furnace turbulence, improving combustion and reducing the time required to complete the same, thus probably reducing carbon in fly ash and danger of slag on the boiler tubes. And it enables anthracite and bituminous coals to be fired separately but thoroughly mixed during combustion.

The furnace is equipped with a special water screen above a dry ash pit of new design. The general ash pit arrangement is so laid out that it can be changed to a slag tap bottom if desired at a later period without major or costly changes.

Condenser

With four stages of steam extraction employed, the condenser with its piping and auxiliaries is considerably reduced in size. For the Holland Station.

which is designed for high vacuum and a good load-factor, there will be only a little over seven-tenths of a square foot of condensing surface per kilowatt capacity of the low-pressure section of the turbine which corresponds to less than six-tenths of a square foot per kilowatt of total turbine capacity. It will be of the single-pass type with horizontally divided water boxes, and will be arranged for reversing the circulating water flow. The tubes will be expanded into both the inlet and discharge tube sheets and the expansion and contraction compensated for by means of expansion joints adjacent to the tube sheets. The condenser will be arranged for bolting directly to the exhaust flange of the turbine.

point, was decided upon after careful consideration in the design of the plant. This method of operation has been tried and proven eminently satisfactory in a 15,000-kw. plant of a subsidiary company in Florida which has been operating for over a year now with a total operating force of seven men (three shifts) and a maximum of four repair men.

The wall which usually separates the turbine room and the boiler room will be omitted in order to allow the operators a greater range of vision.

While the control equipment will not be made fully automatic at first, provision will be made so that it can be easily changed over so as to be fully automatic.

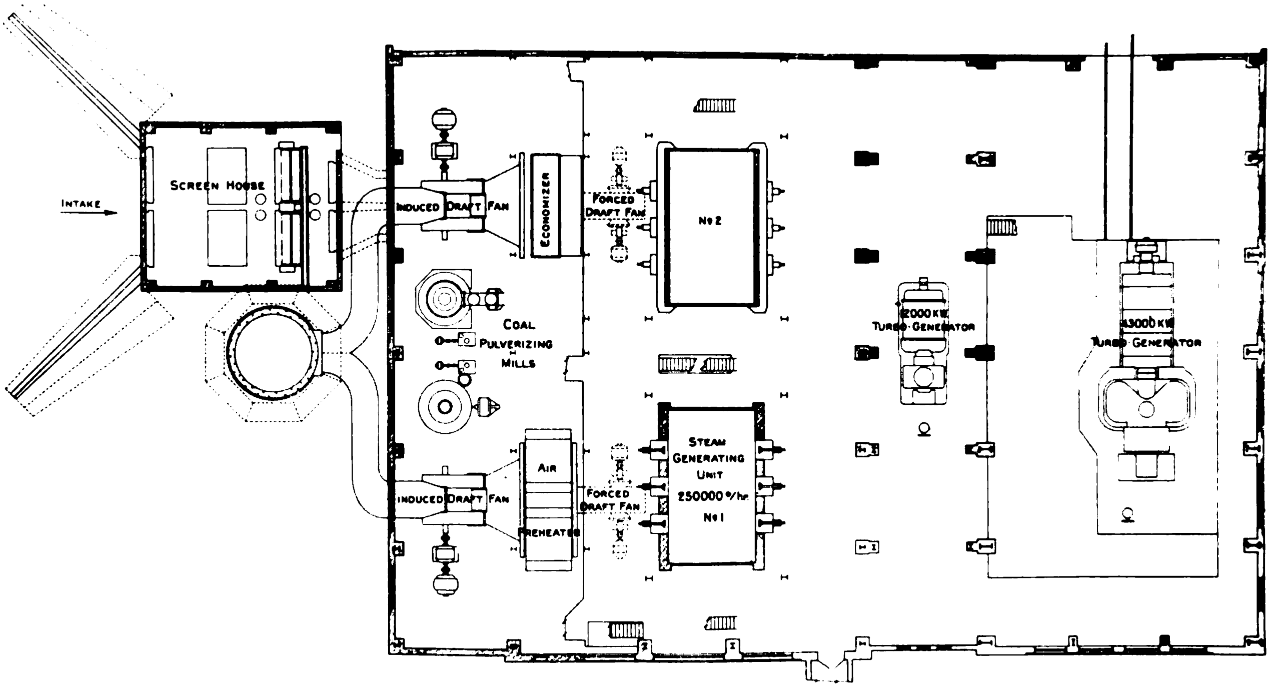


Fig. 6. Plan of Station, Showing Location of Equipment

Auxiliaries Motor Driven

The Holland Plant will feed direct four high-tension and two low-tension (33,000-volt) circuits, tying all other system generating plants and interconnections together. If all of these lines were out of service at the same time the output of the station would not be needed; and if any one of them was in service it would provide ample power for maintaining auxiliary service. In other words, the station auxiliary system will be backed up by all of the other stations in operation on the system and also by the interconnections with other systems. Therefore, no steam-driven auxiliaries will be provided except an emergency boiler feed pump.

Centralized Station Control

Centralized control, in which the chief operating engineer is so located that he not only controls the turbines and boilers with their auxiliaries but also the ingoing and outgoing circuits, all from one

The switchboards for the centralized control are to be placed in the high-pressure turbine bay located in the station where a clear vision of the turbine and boiler room equipment is obtained with the least obstruction. The electrical equipment, including outgoing feeders, generating apparatus, and main feed circuits for the station service power, is to be controlled from this point as well as motors and electrical apparatus vitally necessary for the operation of the boilers and turbine. The space and centralized control requirements do not permit the use of conventional type of power house control switchboard with the usual arrangement of control switches indicating apparatus, and protective relay equipment. In order to compress the number of controls necessary into the space allotted, it was decided to install a semi-supervisory type of control. This system will differ from cable supervisory in that no telephone relays will be interposed between control keys and auxiliary relays. In effect it will be miniature remote control.

The protective relay equipment serving transmission lines, generating equipment, and main station service feed circuits will be concentrated on panels at a convenient point to the entrance of conduit duct-run from the outdoor substation, thus minimizing the conduit space required under turbine room operating floor. Upon this board are to be placed control buttons for use in operating the electrical equipment in emergencies and the auxiliary relay equipment necessary to change the control impulses from the keys at 50 volts d.c. to the control circuits at 250 volts d.c. From the relay board to miniature control board will extend only light circuits in telephone cable. Watthour meters will be placed on the relay switchboard; but synchronizing, speed, voltage and current control, and indicating instruments will be at the miniature control board.

As the station grows it may be advisable to build the usual separate switchboard room and use special operating men for this purpose, and this has been considered and arranged for in the design. Comparison of investment charges show that the installation proposed will cost no more than the regulation layout when the cost of changing to the above future arrangement is considered.

Electrical

The 114-kv. substation, 33-kv. substation, and generator bus structures will be of the outdoor steel angle frame type. The station service cell structures are to be located on two floors above the high-pressure bay, approximately midway between turbine room and boiler room. These structures are of the usual type for their respective services.

Station service power is to be obtained from two sources. The main station service bank is a three-winding type of equipment with 13,200, 2300, and 220-volt windings. This bank is tapped directly off of the general bus through disconnecting switches only. The alternate source of station service power for use during times of shut-down and with sufficient capacity for starting up the plant is to be obtained from a third winding in a grounding bank for the 23-kv. system.

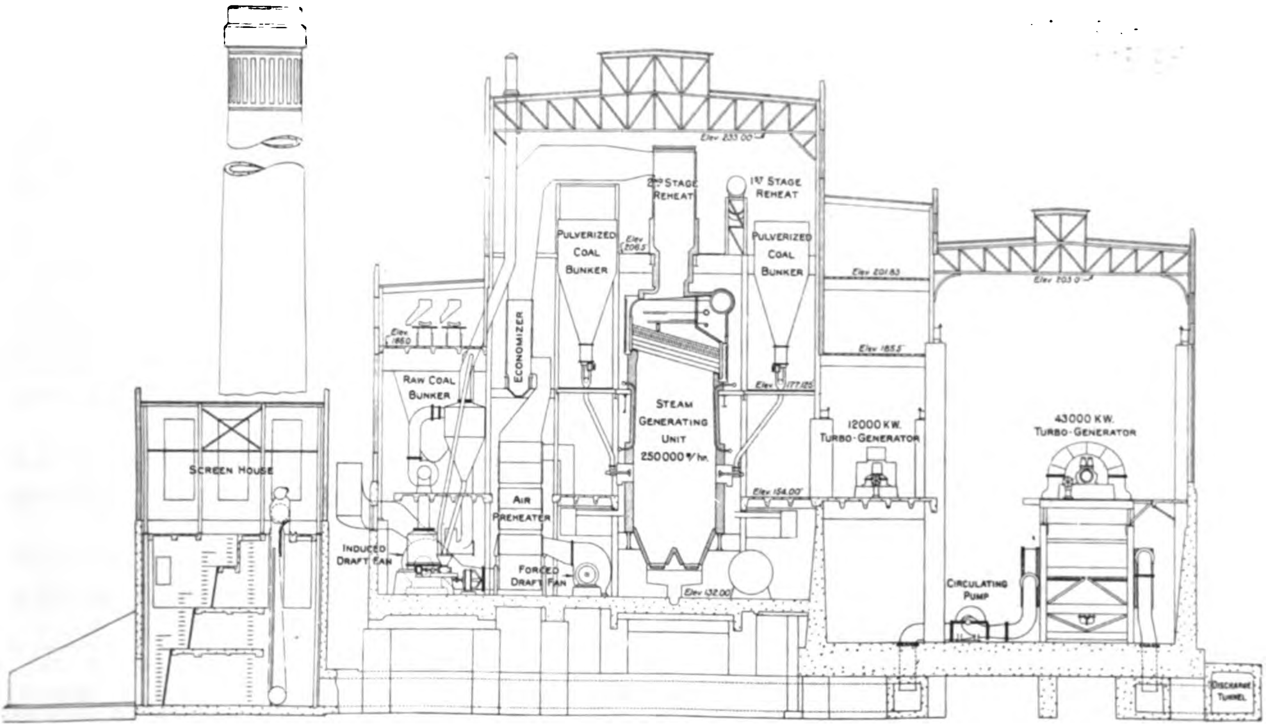

Elev 233.00
2nd Stage Reheat
1st Stage Reheat
Pulverized Coal Bunker
Elev 206.5
Pulverized Coal Bunker
Elev 201.83
Elev 203.0
Elev 186.0
Economizer
Elev 185.5
Raw Coal Bunker
Elev 177.125
Steam Generating Unit 250000 #/hr.
12000 KW. Turbo-Generator
43000 KW. Turbo-Generator
Screen House
Air Preheater
Elev 154.00
Induced Draft Fan
Forced Draft Fan
Elev 132.00
Circulating Pump
Discharge Tunnel

Fig. 7. Elevation of Station, Showing Main Elements of Station Equipment

Synchronizing on the 114-kv. circuits is to be accomplished by means of condenser bushings in the oil circuit breakers with synchronizing networks, thus saving the cost of potential transformers, since no metering is done at this voltage.

General

Figs. 6 and 7 show a plan and a cross-section of the station respectively and indicate the general arrangement. It is of interest to note the location and design of the pulverizing room. This is so arranged that it might readily be called a unit bin system and takes very little building space and is convenient for operation in connection with the rest of the plant.

It might also be noted that the high-pressure turbine is placed on the main turbine room floor under the balcony, and its weight is supported entirely by the floor structure, thus leaving entirely open all space below the turbine for other purposes. On the floor above this machine, switchboard galleries have been installed and we believe the general arrangement will be found economical as to space and cubic contents. A small auxiliary crane for maintenance work is placed over the high-pressure turbine, and the centralized control boards will be placed practically on the line of columns between this turbine and the boilers.

Should trouble occur to the high-pressure turbine, making it desirable to run the plant as a low-pressure plant while maintenance was being made, the fourth-stage heater can be used as a desuperheater. This being a condition which it is hoped will occur but seldom, the changing over of the heater from its usual function to a desuperheater has not been arranged automatically but this can be done should it be desired. Air-tight doors, motor operated with remote control, will be placed directly below the gas reheater which can be used to throw cold air into the setting at this point, thus preventing the overheating of the reheater should the high-pressure turbine trip out.

Construction work on the station is progressing rapidly. The intake and discharge tunnels for circulating water and all foundations and part of the building have been completed. It is expected that the station will go into operation about October, 1929.

PRINCIPAL EQUIPMENT FOR HOLLAND STATION

Turbine and Condenser

One General Electric cross-compound turbine-generator unit having a total capacity of 55,000 kw. consisting of a 11,800-kw. 85 per cent p-f. 13,880-kv-a. 13,200-volt high-pressure element operating at 3600 r.p.m., and a 43,200-kw. 85 per cent p-f., 50,820 kv-a. 13,200-volt low-pressure element operating at 1800 r.p.m., with direct-connected exciter of sufficient capacity to excite both generators.

Two General Electric surface air coolers for the generators of the high-pressure and low-pressure elements respectively.

One 250-kw. General Electric motor-generator exciter set operating at 1200 r.p.m.; 250-volt shunt-wound d-c. generator.

One Ingersoll-Rand single-pass surface condenser equipped with horizontally-divided water boxes, extra nozzles for reversing water flow, quick-opening water box doors, and integral hot-well chamber. Condenser to have 31,600 sq. ft. of tube surface made up of 7,310 Admiralty metal tubes, ¾" O.D., No. 17 B.W.G., 22 ft. long.

Boilers, Reheaters, etc.

Two Babcock & Wilcox wrought steel sectional cross drum boilers, each having an effective heating surface of 798 sq. ft. and designed for a working pressure of 1400 lb.

Two Babcock & Wilcox superheaters, built for a working pressure of 1400 lb. and designed to superheat the steam from the boilers to a temperature of 750 deg. F.

Two Babcock & Wilcox reheaters, each having a heating surface of 11,450 sq. ft. and built for a working pressure of 425 lb.

Two Babcock & Wilcox heated-type reheaters, each containing 1508 sq. ft. of heating surface and built for a working pressure of 425 lb. on the low-pressure side and 1400 lb. on the high-pressure side.

Two Foster Wheeler economizers, each having 11,880 sq. ft. of heating surface, and built for a working pressure of 1400 lb.

Two Foster Wheeler plate-type sectional air heater units, each containing 32,450 sq. ft. and consisting of ten sections.

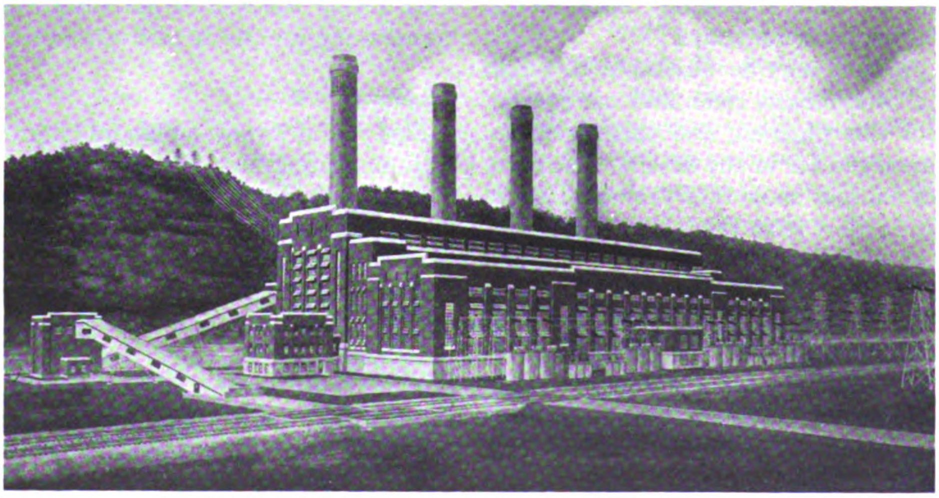
Two Combustion Engineering Company furnace and boiler settings, including water walls, burners, ash hoppers, ash hopper gates, etc.

Pulverizers, etc.

One combustion Engineering Company's Raymond air-swept, 6-roll pulverizing mill.

One Fuller-Lehigh No. 70 air-separation type, gear-driven pulverizing mill.

One Fuller-Kinyon transport equipment to serve four pulverized coal storage bunkers ahead of two boilers.



Architect's Drawing of Holland Station

Volt-ampere Measurement

Interest in Volt-ampere Measurement Promoted by Power-factor Considerations—Adaptation of Standard Integrating Wattmeter to Purpose—Influence of Leading and Lagging Power-factor and Phase Sequence

By JOHN AUCHINCLOSS
Switchgear Engineering Department, Philadelphia Works
General Electric Company

WITH the growth of alternating-current distribution and consequent increase in the use of induction motors, power companies have been compelled in the interests of mutual economy to initiate an educational campaign to show to their customers the advantages which high power-factor offers to both producer and consumer. While the consumer's conception of power-factor may be somewhat hazy, the record of a special integrating meter, somewhat similar to the watthour meter on which his charges are based, will clearly show him that he has consumed an additional something which has cost the power company money to produce. Whether this money be direct charges for coal consumption at the generating station or indirect charges for interest on unnecessarily excessive investment in generating and distributing equipment may be beyond the technical knowledge of the average present-day consumer; but he does know that if his power-factor becomes low his bills become relatively higher with respect to his consumption of power.

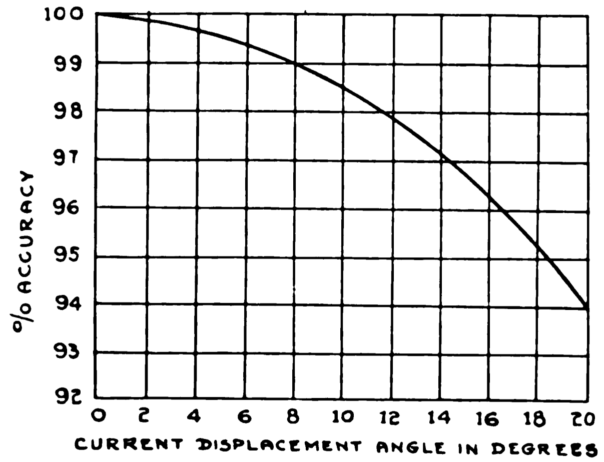


Fig. 1

Various methods have been devised to encourage the consumer to maintain high power-factor. Among the earliest was the recording power-factor meter. While this device is very useful as a guide in the general operation of a plant, it unfortunately does not integrate and is therefore not particularly suitable for determining the charges.

For integration purposes, a combination consisting of a watthour meter and a reactive volt-ampere-hour meter is frequently used. The latter is merely a watthour meter to which potential is supplied in the proper phase relationship to cause it to register in proportion to the reactive component of the line current.* From the reading of both meters the *average* kilovolt-amperes over a period of time may be computed. The *average* kilovolt-amperes as thus computed is the vector sum, not necessarily the arithmetical sum, of the active and reactive components over the entire period. Where the power-factor fluctuates considerably, this method is therefore not entirely accurate. To arrive at a more nearly accurate solution under these conditions, a demand has arisen for a device which will integrate directly in kilovolt-ampere hours; and many ingenious contrivances have been suggested for the purpose. Most of these devices however involve special construction and are practically untried in actual operating service. To utilize a device of high proven accuracy over long periods, whose characteristics are well known, and for which repair parts may be readily obtained, the following arrangement has been devised whereby the regular standard integrating wattmeter may be used for the purpose.

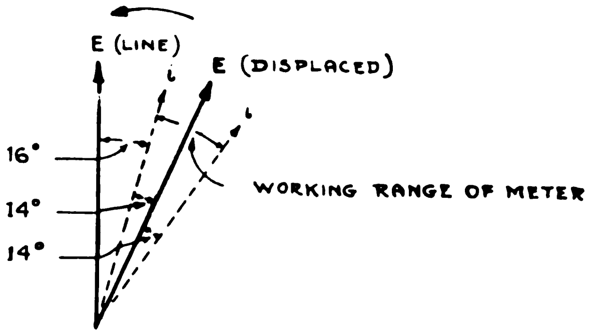


Fig. 2

It is well known that for small increases in displacement angle near unity power-factor, the cosine changes by almost imperceptible increments up to about 14 deg. From Fig. 1 it is apparent that at this displacement angle the cosine or power-factor is approximately 97 per cent, and the reading of a wattmeter attempting to measure kilovolt-amperes would be about 3 per cent in error. At unity power-factor, however, the meter would register the true kilovolt-amperes, within its known limits of accuracy. Most industrial plants have at least a fairly constant range of power-factor. Suppose for the sake of illustration, and also simplicity, the mean to be 86.6 per cent with a fairly wide range, say of 14 deg. either way. A power-factor of 86.6 per cent represents a lag angle of 30 deg. The 30 plus 14 deg., equal to 44 deg., angle corresponds to a power-factor of approximately 72 per cent. In the other direction the 30 minus 14 deg., equal to 16 deg., angle corresponds to a power-factor of approximately 96 per cent. If therefore we connect a single-phase wattmeter on a single-phase circuit with its potential coil energized from a voltage displaced in time phase 30 deg. behind the normal voltage of the circuit, the instrument will read the true kilovolt-amperes at 86.6 per cent power-factor, since at this power-factor its current and potential are exactly in phase; just as conversely at unity power-factor it will give a reading corresponding to a power-factor of 86.6 per cent. With normal watt voltage impressed upon it, however, the meter would record only 86.6 per cent of the total kilovplt-amperes. At 30 plus 14 deg. lag, the watt connection would give a torque proportional to cosine 44 deg. or 72 per cent, whereas with the displaced voltage the torque for the same line power-factor would be proportional to cosine 14 deg. or 97 per cent, or 3 per cent less than the true kilovolt-amperes. Similarly at 30 minus 14 deg. lag, the watt connection torque is determined by cosine 16 deg. or about 96 per cent power-factor; while for the displaced voltage it is cosine 14 deg. or again 97 per cent, which is also 3 per cent less than the true kilovolt-amperes. At high line power-factors, therefore, the wattmeter and kilovolt-ampere meter experience substantially the same torque. If, however, the meter is originally calibrated so that at unity power-factor it is 1.5 per cent fast, then with the displaced voltage at line power-factors of 97 and 72 per cent it will be only 1.5 per cent slow instead of 3 per cent. It will also be 1.5 per cent fast at 86.6 per cent power-factor, but for intermediary values between 86.6 and 97 per cent on one side and 86.6 and 72 per cent on the other, it will approach much closer accuracies. This will be apparent from a brief reference to Fig. 2.

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*For a description of these meters, see "Measuring the Reactive Component," by John Auchincloss, GENERAL ELECTRIC REVIEW, April, 1924, p. 263.—ED.

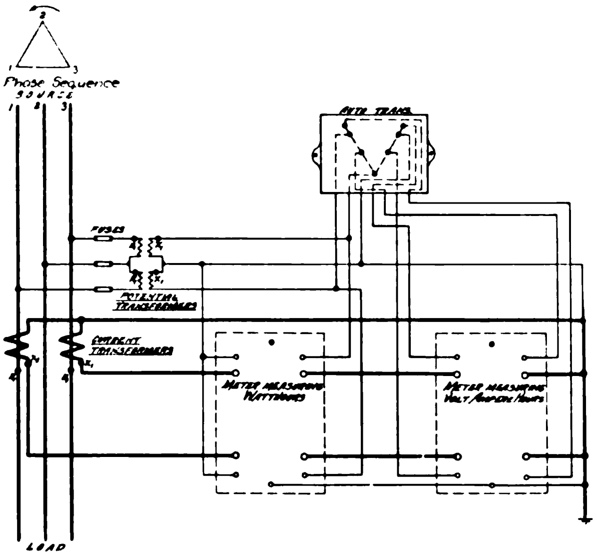


Fig. 3

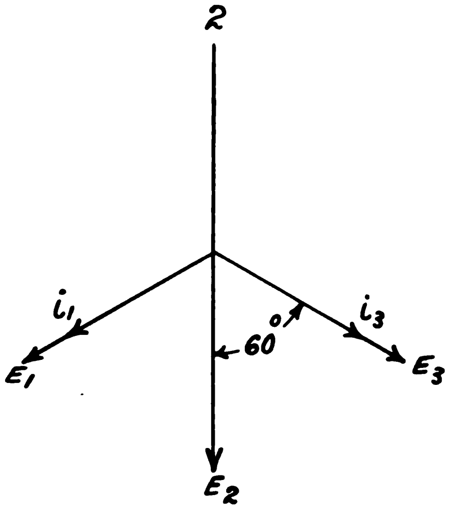


Fig. 4

While so far single-phase circuits have been of too little concern to apply the foregoing idea (by phase-splitting devices or otherwise), nevertheless on three-phase circuits, over which larger quantities of power are usually delivered, its application is becoming fairly common. On such circuits the usual method of obtaining the necessary displaced voltage utilizes small auto-transformers of sufficient capacity to carry the necessary burden. Applied to a three-phase three-wire circuit for a mean power-factor of 86.6 per cent, the connections are as shown in Fig. 3. The volt-ampere-hour meter is a standard two-coil meter operating on the Aron principle (two-wattmeter method), but calibrated 1.5 per cent fast at unity power-factor. The two auto-transformers are combined in a common case. Their full winding gives 127 volts with 110 volts impressed on the 110-volt taps. This arrangement gives 110 volts from the end of one winding to the 63.5-volt (mid-point) tap of the other, but displaced 30 deg. from the normal line voltage (127 volts × cosine 30 deg. = 110 volts).

In Fig. 4 is the vector diagram representing the circuit connections in Fig. 3. It will be noticed that at unity power-factor the current i_1 is in phase with the voltage E_1 while the current i_3 is 60 deg. displaced from its operating voltage E_2. At unity power-factor, then, the torque on the common shaft is proportional to

$$E_1\, i_1 + E_2\, i_3 \cos 60^\circ = E_1\, i_1 + 0.5\, E_2\, i_3$$

or on balanced load it is

$$1.5\, Ei$$

corresponding to a fictitious power-factor of 86.6 per cent when the true power-factor is actually unity.

When the true power-factor is 86.6 per cent with lagging current, corresponding to a lag of 30 deg., the condition becomes as is shown in Fig. 5, and the torque is equivalent to

$$E_1 i_1 \cos 30^\circ + E_2 i_3 \cos 30^\circ = 0.866\, E_1 i_1 + 0.866 E_2 i_3$$

or on balanced load

$$1.732\, Ei$$

which is the same as the watt connection when operating on unity power-factor. In other words, at 30 deg. lag with displaced voltage, the meter torque (by disregarding the real power-factor) simulates the watt torque at unity power-factor, which is the equivalent of the kilovolt amperes.

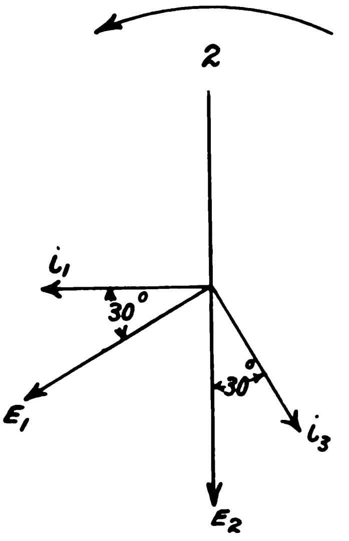


Fig. 5

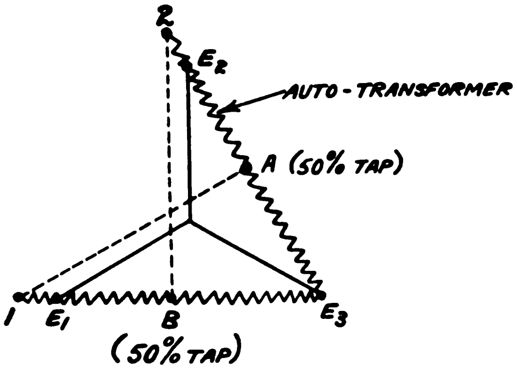


Fig. 7

It should be further observed that if the currents were leading, instead of lagging, by the same angle the torque on balanced load would be

$$Ei \cos 30^\circ + 0 = 0.866\, Ei$$

corresponding to a power-factor of 50 per cent, instead of a total kilovolt-ampere load indication of 1.732 *Ei*. However, were the sequence arrow shown in Fig. 5 drawn in the opposite direction, it is obvious that the meter would read correctly with leading currents and erroneously with lagging currents. Its connections are therefore dependent upon the phase sequence of the system.

On the other hand, if the phase sequence is in the reverse order of that indicated in Fig. 5, as shown in Fig. 6, then it is apparent that the voltage E_3 must be substituted for the voltage E_1, and that E_3 must be used with the meter element whose current circuit is connected in phase 3 as must the voltage E_2 be used with the current of phase i_1. At 30 deg. lag the torque is then

$$E_3 i_3 \cos 30^\circ + E_2 i_1 \cos 30^\circ = 1.732\, Ei$$

on balanced load, which is the correct kilovolt-ampere reading.

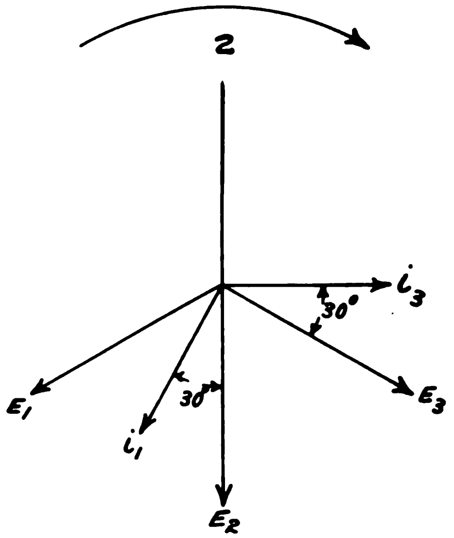


Fig. 6

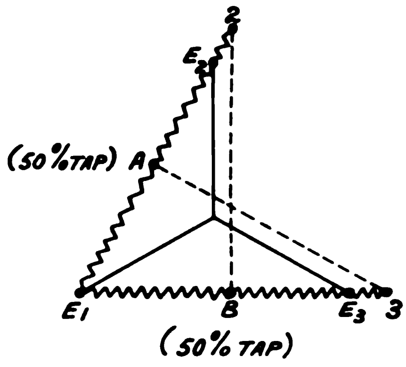


Fig. 8

Another representation of the meter potential connections from which Fig. 3 is derived is shown in Fig. 7. The upper meter element has its current coil connected in phase 3, so that its potential coils must be connected across *2*—*B* in Fig. 7, or E_2 vectorially in Fig. 4. Since the current coil of the lower element is energized from phase *1* its potential element must take energy from the voltage *1*—*A* in Fig. 7, or E_1 in Fig. 4.

However, if the sequence were in the opposite direction the autotransformer connected across potential *2—3* must be removed and connected across *1—2* to give the required voltage E_3 shown in Fig. 8. In other words, the common point of the autotransformer must be at phase *1*, instead of *3* as shown in Fig. 7, which gives a voltage *A—3*, corresponding to E_3 in Fig. 6 and *2—B* corresponding to E_2. To correct for opposite phase sequence, therefore, it is necessary only to interchange the autotransformer connections at phases *1* and *3* and also to interchange the voltage applied to the two elements of the meter.

Where the mean power-factor differs from 86.6 per cent, obviously taps differing from those shown in Figs. 7 and 8 must be selected to give the proper voltage displacement and value, which means that in many cases the autotransformer is a special one designed to suit the conditions of a particular installation.

From Fig. 1 it will be noted that for displacement angles exceeding 14 deg., the per cent power-factor begins to fall off rather rapidly and consequently the accuracy obtainable with the meter just described is considerably reduced. To take care of wider power-factor fluctuations than this meter will handle with good accuracy, the same principle may be applied to a meter equipped with a double shaft each one of which, with its associated current and potential elements, operates within a zone corresponding in range to that of the previously described single-shaft device. The two shafts of this meter are geared to the recording mechanism in such a way that only the one which is experiencing the greater torque drives the mechanism forward.

Automatic Brake Permits Push-button Control of Super-synchronous Motors

An automatic brake eliminates the necessity for manually braking the rotating stator of super-synchronous motors without sacrificing any of the desirable features of hand braking.

The automatic brake mechanism consists of an upright standard which supports a vertical shaft the lower part of which is threaded. When it is revolved it transmits motion, through a trunnion block, to a series of levers attached to the brake band. The driving motor for the brake is mounted on the side of the standard and is geared to the screw shaft. A wheel is mounted on the end of the shaft so that hand-operation may be employed at any time.

When the brake is being released, the trunnion block travels upward on the screw and is stopped by the tripping of a limit switch when sufficient clearance has been obtained between the brake band and the motor frame. In tightening the brake, the trunnion block moves down on the screw, automatically applying tension to the brake band through the combination of levers and weights until the action is stopped by a limit switch. It is impossible for the brake to apply more torque than the amount corresponding to the weights on the brake lever. By adjusting these weights it is possible to vary the starting time of the motor over a reasonable period; *e.g.*, from 5 to 40 sec.

The balancing of the weight and the closing of the band around the frame take place gradually. Over two seconds elapse after the band makes contact with the frame before full tension is established. This does not include the time taken to remove the slack from the band, which requires a few seconds. The tension is applied at the same speed, regardless of the amount of weight on the lever. Consequently there is no sudden application of torque to the driven machine.

Any slight expansion in the brake band is automatically compensated. When the stator frame has been brought to rest and the load has been accelerated to full speed, the driving motor is again started and the brake band is given sufficient tension to lock the motor frame rigidly and thus prevent any slipping that might otherwise be caused by shocks produced by the load. Thus, with the automatic brake the super-synchronous motor may be started or stopped by a push-button, and hand operation is eliminated except when desired.

The super-synchronous motor on which this brake is used is designed for driving loads where synchronous motors can be advantageously used, where loads require more than full-load torque before synchronism is reached, and on which it is desired to limit the power demand during the starting period to approximately full-load values. This is possible by reason of the fact that the motor is so constructed mechanically that its pull-out torque is also its starting torque. Typical applications are found in the drive of centrifugal and other pumps where by-pass connections are omitted; air compressors where unloading valves are omitted; vacuum pumps; mine fans and other large blowers; crushing, grinding, and pulverizing machinery in cement mills, rock crushing plants and ore dressing mills; paper-mill pulp beaters; flour-mill and rubber-mill line shafts; machines characterized by heavy flywheel effects; and machines difficult to start when stopped loaded with material.

The Future Trend in Ship Electrification

By F. V. SMITH
Federal and Marine Department, General Electric Company

The spectacular performance of recent "Electric Ships" warrants us in looking for a brilliant future for this type of marine propulsion; we therefore hope to pay more attention to this subject in our future issues and have arranged for further articles by the present author.—EDITOR

THE first modern turbine electrically driven passenger liner made its appearance on the high seas in January, 1928; it was an event of the most far reaching importance in the marine-engineering field and quite as revolutionary an innovation as the first turbine-driven passenger liner in the North Atlantic trade route 22 years ago.

The application of electricity on land has revolutionized our industries; multiplied our labor forces; enlarged our opportunities; and enriched and stimulated our lives. Up to the present time the merchant marines of the world have not kept pace with this great modern trend. The majority of the ships which sail the seas today are powered with types of machinery hopelessly inadequate to serve the needs of an enlightened civilization.

The development of the potential international and domestic trade possibilities is molded into a dynamic reality only by means of efficient transportation; the means of transportation however must first be set up before the trade can materialize. In the competitive ship lanes, speed, economy, and regularity of service are requisite factors for obtaining mail contracts, the dispatch of valuable cargo, and in catering to the desires of first-class passenger traffic.

Prior to 1907 the fight for supremacy on the North Atlantic was being waged with reciprocating engined ships fitted with hand-stoked coal-burning furnaces. The weight and space factors of this type of marine machinery had blocked further progress and an apparent deadlock had been reached. Then in 1907 the *Mauretania*, the first turbine direct-driven ship took to the seas; it was one of those courageous steps, lacking in precedent, that so often proves to be the potent factor in changing the entire design standards of an industry—or, of the habits and thoughts of a people. And this is exactly what took place on the North Atlantic. All the large ocean greyhounds which followed, the *Majestic*, *Leviathan*, *Aquitania*, *Berengaria*, *Olympia*, *Paris* and *Isle de France* were similar in design and remain as concrete examples of the far reaching results of one great venture. The power of these vessels ranges from 60,000 to 80,000 horsepower whereas the former heights reached by the reciprocating engined ships was but from 25,000 to 45,000 horsepower.

The fuel economies on these new vessels was of secondary importance and compromises were made in every direction to obtain the main objectives—power and speed. Turbine speeds were selected that were too low, and propeller speeds that were too high for satisfactory economy; the turbines were split up into many casings and cross connected by a multiplicity of pipe lines, increasing the number of exit and entrance losses and packing losses; backing power could be obtained only by building another set of turbines especially for that purpose, or, by including a backing turbine in the same casing with the elements used for ahead operation. In choosing between the two, the latter was used and another serious compromise ensued—that of cutting down the backing power to a minimum—in some cases to as low as thirty per cent of the ahead power. From a mechanical point of view and complexity of design these huge units show a marvel of engineering skill. As to their having played one of the most important parts in the development of shipping there can be no doubt; twenty-two years is a long time for one type of machinery to hold the sway; so in these days of rapid engineering advancement we are not surprised when something new takes ascendency over the old.

During this interesting period of development of the large ocean liner, the United States has left the North Atlantic trade route for the European nations to conquer. We were busy developing our industries, putting into effect methods of mass production; emancipating labor from drudgery; finding ways and means to apply electricity to every purpose; and developing the central station idea for the generation of power in ever increasing quantities. With great vision our industries have been guided to the highest peaks of success. Electricity has become a part of our daily lives—we cook by electricity—we read by its light—we enjoy the nightly radio programs; we as a nation have developed an electrical conscience and think in terms of electricity.

It is the most natural thing in the world therefore that the modern electric ship was to be an American idea and conceived with the same high motives and aspirations. There is romance in the development of the electric ship and although we can not yet visualize in a concrete way by pointing to great numbers of merchant vessels so equipped, yet it has one of the most substantial backgrounds of practical experience.

Many years ago W. R. L. Emmet had a vision—that of ship electrification; he foresaw with clear vision the tremendous advantage of driving a ship electrically—rapid maneuverability; full power backing; the use of a high-speed turbine operating at its maximum efficiency; the low-speed propeller and its high efficiency; the use of one turbine-generator at reduced powers; the adaptability of such a turbine to high pressure and superheat and its increased economies thereof. With clearness of vision and a complete knowledge of what had been accomplished in central station work, in the steel plants where motors were used to drive rolling mills, and the methods of control, he approached the U. S. Naval engineers.

The United States Navy agreed to try out this form of drive on a ship of 6,000 horsepower—the collier *Jupiter*. It was an experiment on the part of the Navy but not in the mind of Mr. Emmet. The experiment was a complete success—so much so in fact that the Navy Department decided to so equip its later battleships; this was in the year 1913. The collier *Jupiter* later became our first airplane carrier and was renamed the *Langley*. Five years after the launching of the *Jupiter* the *New Mexico*, a first line battleship was launched. It too was a great success and even after ten years of service it won the engineering trophy for excellency in engineering. Many electric battleships followed the *New Mexico*—the *Colorado*, *Maryland*, *Tennessee*, *West Virginia* and *California*.

Then the Coast Guard Service became interested and they electrified their new cutters. Electric drive was chosen because of the rapid maneuverability; the service was severe and they never knew when they would have to work in near beaches in their life-saving work—immediate possession of the propeller at all times was therefore of the utmost importance. As part of the great war measure, in building the bridge of ships, we were also called upon to manufacture turbine-electric drive units for several cargo boats; these boats are still being operated successfully.

Then came one of the most stupendous schemes ever concocted in the minds of the naval engineer—the electrification of a ship of 180,000 horsepower; these new ships were to be battle cruisers—super fighting units. The limitation of armaments program altered the original plans but not the power. We were allowed to retain two of these vessels as airplane carriers and they were completed as such; the designers of the electrical equipment, even after the equipments were built could not tell what the ultimate capacity of the units might be and simply gave them a nominal rating of 180,000 horsepower at the propeller shafts; the boiler manufacturers were also working in unknown regions and were willing to carry their operating curves to nominal values only. Actual tests of these units were therefore awaited with great anxiety. A few of the records made by the *Lexington* have already become known and they startle the imagination and carry us into new fields of speculation regarding the future. The *Lexington* developed the unprecedented amount of 210,000 horsepower at the propeller shafts and attained a speed of 34.62 knots or approximately 40 land miles per hour. Compared to the largest ocean liners the power amounts to 262 per cent of that of the largest Atlantic liners. The *Lexington* also produces 31 per cent more power than the largest naval vessel heretofore built.

In considering the question of power from an electrical point of view no one knows what the limitations are; all the electrical engineer can tell is that in the year 1928 a ship is operating with his equipment in which the motors on one propeller shaft generate 52,500 horsepower. Is the limit of power in the future to lie in the direction of the propeller, the hull, or the boilers? These are questions that the naval architects are asking today.

Knowing that the genius of our electrical engineers has solved the problem of power for ships, that carry us to realms unknown when the *Mauretania* was launched 22 years ago, it is well that we look towards the future and visualize the full import of the momentous events which have taken place during the year 1928.

One of the most forward and far reaching events that has ever transpired in the annals of American shipping took place when the International Mercantile Marine decided to build three palatial liners of the transatlantic type for their Panama-Pacific lines, and to electrify them completely according to modern standards of efficiency and power house practice.

The first vessel to be completed was the S. S. *California* which went into commission in January, 1928. Its great success came from directions that were at first not anticipated; it had the greatest popularity with the passengers and they sung its praises loudly. The ship rode easily through the worst storms, was vibrationless and noiseless; the passengers marvelled at the new order of things—told their friends of a wonderful trip on a new kind of ship. The result was that the booking offices were holding passages five months in advance. The Easterner wanted to become better acquainted with the Westerner and the Westerner wanted to look over the Easterners; rapid, modern transportation awakened a new interest in sea travel and trade possibilities that were lying dormant were awakened.

The second vessel of this wonderful fleet of three vessels is now on her maiden voyage, booked to capacity. It is named the *Virginia*. The third ship is now building and it is expected that it will be commissioned in the fall of 1929.

The maritime nations of the world have watched the results of the *California* with the greatest interest.

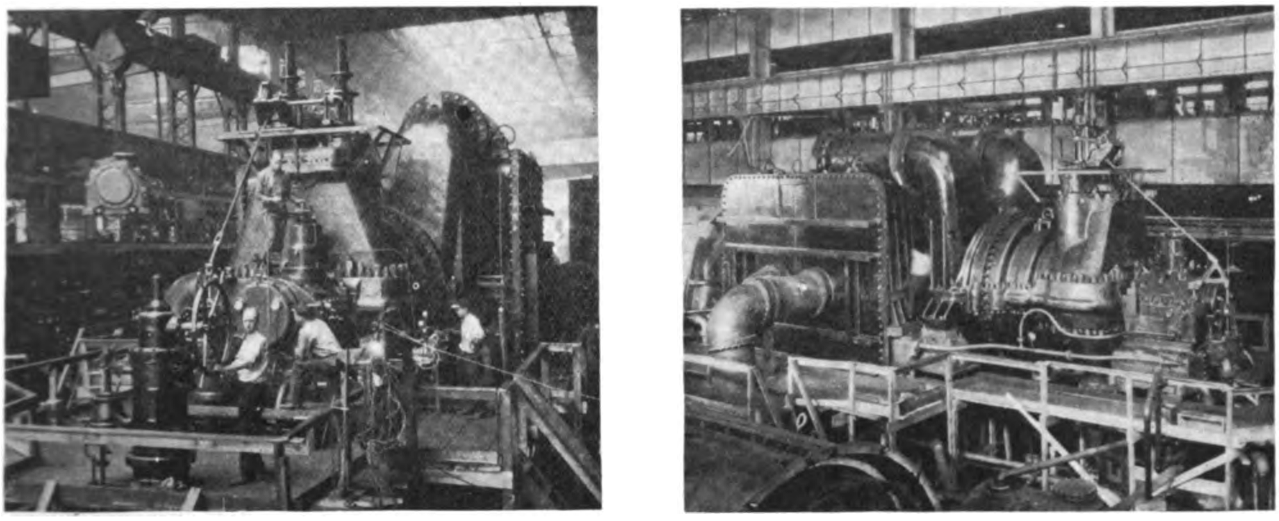
The Peninsular and Oriental Line are building a similar vessel for their trade route between England, India and Australia. It is named the *Viceroy of India* and is to be commissioned soon. The electrical machinery for this vessel was built by the British Thomson-Houston Co.

Then came the most startling news of all. The White Star Line laid the keel for a new 1000-foot passenger liner for the North Atlantic; more luxurious and speedier than ever dreamed of before; and Lord Kyslant announced it was to be electrically driven; One-thousand-foot liners, unlimited power at the naval architect's disposal—what does the future portend? And what is the answer on the North Atlantic? There is but one answer and that is that the first electrically driven passenger ship on this chosen ship lane of the world will establish new standards that others must eventually follow. Then twenty-two years from today—what?

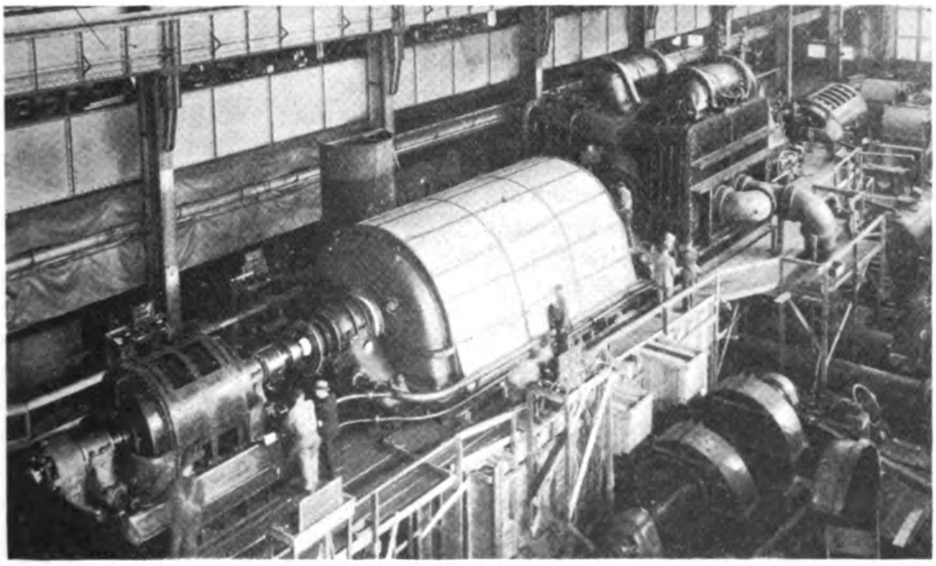
In this country, our shipping concerns are undergoing a great awakening and many new passenger liners are being projected. One of the recent contracts to be let was that for a new passenger liner for the Grace Line—it too is to be all-electric. It will run between New York and the West Coast of South America.

These events are happening with such speed we are likely to overlook their true significance; to one who is not a shipping man, who has never traveled on the seas, he may want just an insight into what an electric ship is and how it differs from other types of vessels. We are therefore planning the future publication of other articles on electric ships in subsequent issues of the REVIEW.

Testing a 94,000-kw. Turbine-generator



Views of the Turbine End of the 94,000-kw. Unit Built for the Southern California Edison Company Taken During Test Run at the Factory



A General View of the Turbine-generator, Showing Set-up for Factory Tests

New Theory of Transformer and Autotransformer Circuits

By A. BOYAJIAN
General Transformer Engineering Dept., Pittsfield Works
General Electric Company

ABSTRACT

THE conventional equivalent circuit of transformers (or autotransformers) serves certain useful purposes, but completely fails to represent the fundamental characteristic and most important function of transformers and autotransformers, namely, current and voltage transformation. The theory of a new kind of equivalent circuit is developed below, capable of reproducing all the performance characteristics of transformers and autotransformers. The following two theorems are developed:

(*a*). For any given transformer or autotransformer, there exists a completely equivalent impedance network having the same characteristics, that is, capable of performing the same current and voltage transformation with the same exciting current, impedance, regulation, and efficiency from no load to full load and short circuit.

(*b*). For any given impedance network, a completely equivalent transformer or autotransformer can be specified.

Conversion formulas are given for the equivalent networks of three-terminal autotransformers, and for the equivalent autotransformers of three-terminal networks. The general method for other cases is indicated.

The new conception here outlined is of value not merely in affording a more comprehensive grasp of transformer and autotransformer theory, but also in facilitating the solution of complicated transmission networks involving transformers or autotransformers, by making it possible to replace the transformer or autotransformer completely by its equivalent impedance network, after which the characteristics of the resulting network are solved by well-known analytical or mechanical methods.

An excellent application of the theory to the solution of railway circuits is described by D. R. MacLeod in a companion article on that subject.*

The more useful formulas are collected near the end.

Introduction

Fig. 1 represents the conventional equivalent circuit of a transformer or autotransformer, with primary leakage impedance Z_p, secondary leakage impedance Z_s and magnetizing or mutual impedance Z_m, reduced to one-to-one ratio basis. Obviously, such an equivalent circuit is incapable of representing the current and voltage transformation of the apparatus. When it is considered that current and voltage transformation is the main characteristic for the sake of which transformers and autotransformers are built, the equivalent circuit which fails to represent it appears very limited indeed. Fortunately, it is found that a "completely equivalent" circuit can be formulated in all cases. To illustrate this, we may consider the autotransformer shown in Fig. 2(a), having a 1:2 ratio of transformation, with low-voltage terminal *L*, high-voltage terminal *H*, and neutral or common terminal *N*. This autotransformer may be thought of either as a single-phase unit or as one phase of a three-phase unit.

Let Rating	= 1000 kv-a. output per phase as autotransformer.
Voltages	= 2200 volts high-voltage leg voltage (*N-H*).
	= 1100 volts low-voltage leg voltage (*N-L*).
Load Current	= 454.5 amp. in high-voltage line.
	= 909 amp. in low-voltage line.
Magnetizing Current	= 2.013 per cent based on output as autotransformer.
	= 9.16 amp. in H.V. Lines or,
	= 18.3 amp. in L.V. Lines.
Core Loss	= Negligible.
Reactance	= 4.13 per cent based on output as autotransformer.
	= 0.05 ohms based on L.V., or
	= 0.20 ohms based on H.V.
Resistance	= 0.827 per cent based on output as autotransformer,
	= 0.01 ohms based on L.V. or,
	= 0.04 ohms based on H.V.

The conventional equivalent circuit of this autotransformer is shown in Fig. 2(b). The characteristic constants are shown in terms of percentages, but of course they could also be given in ohmic values reduced to a common basis using the square of the ratio of transformation as the conversion factor. Such an equivalent circuit, however, not only does not accomplish any current or voltage transformation, but does not even attempt it, and therefore the equivalence is in a very limited sense indeed. In fact, the theory underlying the diagrammatic representation of Fig. 2(b) does not even hint at the possible existence of an equivalent impedance network capable of accomplishing the same or any current and voltage transformation.

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*See "New Equivalent Circuits for Autotransformers and Transformers with Tapped Secondaries," by D. M. MacLeod, on page 120 of this issue.

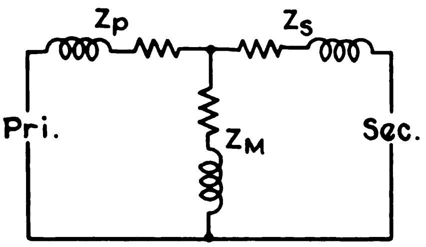

Fig. 1. Conventional Representation of the Equivalent Circuit of a Transformer

In Fig. 2(c) is shown the impedance network which is the "*complete equivalent*" of the autotransformer of Fig. 2(a). Before explaining how it was derived, we may do well to show that it really is a "complete equivalent."

Characteristics of the Network of Fig. 2(c)

The characteristics of the autotransformer are completely determined, mathematically, when the self and mutual impedances of the primary and secondary circuits are given. Hence, if the equivalent circuit duplicates the self and mutual impedances of the primary and the secondary, the equivalence will be established. We shall, however, go further, and show how the various important performance characteristics are duplicated.

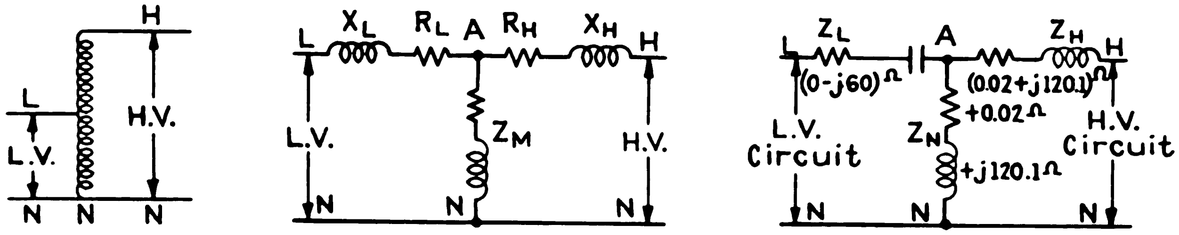

Fig. 2(a) Fig. 2(b) Fig. 2(c)

Fig. 2. Conventional Diagrams of Transformers

Fig. 2(a). Autotransformer. Fig. 2(b). Equivalent circuit or network for transformer or autotransformer.
Fig. 2(c). Completely equivalent network of autotransformer shown in 2(a).

1. No-load Characteristics

(*a*). Self or Open-circuit Impedances—Exciting-current Characteristics.

With 1100 volts applied between the low-voltage terminals L and N, an exciting current flows (through the branches LA and AN in series) equal to

$$\text{L.V. exciting current} = \frac{1100}{-j60+0.02+j120.1}$$

$$= \frac{1100}{j60.1+0.02} = -j18.3 \text{ amp.}^{(1)}$$

This will be recognized as the specified exciting current of the autotransformer on the low-voltage side. Hence, the L.V. side of the equivalent network has the same self-impedance or open-circuit impedance as the L.V. side of the autotransformer.

If the high-voltage side of the equivalent network is excited, voltage being applied between H and N, we get

$$\text{H.V. exciting current} = \frac{2200}{0.02+j120.1+0.02+j120.1}$$

$$= \frac{2200}{0.04+j240.2} = \frac{2200}{j240.2} = -j9.15 \text{ amp.}^{(2)}$$

which is the specified value for the autotransformer. Thus, it is seen that the H.V. side of the equivalent network has the same self-impedance or open-circuit impedance as the H.V. side of the autotransformer.

(*b*). Mutual Impedance, or Voltage Transformation.

To obtain the mutual impedance of the primary and secondary circuits, we excite one circuit and observe the voltage across the other circuit. To apply this test, let the low-voltage side of the equivalent network be excited. Referring to the diagram, Fig. 2(c), it will be seen that since with excitation across L and N there is no current in the branch AH, therefore, the voltage appearing across the high-voltage terminals (H to N) will be the same as the drop across AN. Hence, with 1100 volts applied across the low-voltage terminals L and N, the voltage across the high-voltage terminals H and N will be

$$\text{H.V. no-load voltage} = (-j18.3+0.0608)\,(0.02+j120.1)$$

$$= (2198+j7) \text{ volts.}$$

---

(1) More exactly, the current is $(-j18.3+0.0608)$ amperes, the minute in-phase component of the current being due to the resistance of the winding in the present case.

(2) The minute in-phase component of the exciting current due to the resistance of the winding is ignored. Most of the calculations in this article are made with the aid of the slide-rule, as such are sufficient to illustrate the points involved.

The voltage rating of the high-voltage circuits of the autotransformer being 2200 volts by mutual induction from 1100 volts low-voltage, based on turn-ratio, it is seen that the equivalent network duplicates it exactly, with the added refinement that the minute regulation of the autotransformer due to the leakage impedance drop produced by the exciting current is also indicated.

It is concluded, therefore, that the equivalent network duplicates the mutual-impedance as well as the self-impedances of the primary and secondary circuits of the autotransformer, and is therefore its complete equivalent.

The practicing transformer engineer thinks not so much in terms of self and mutual impedances as in terms of excitation and leakage impedance characteristics, or no-load and short-circuit characteristics; the full-load characteristics automatically following from these two. The no-load characteristics, that is, the exciting currents and voltage transformation ratio, have already been explicitly indicated, so that only the leakage impedance or short-circuit characteristics remain to be shown explicitly.

(2). *Leakage Impedance Characteristics and Current Ratio*

(*a*). Leakage Impedance.

To show that the equivalent network of Fig. 2(c) has the same leakage-impedance (or short-circuit impedance) as the autotransformer under consideration:

Short-circuiting the high-voltage terminals (H to N) and measuring across the low-voltage terminals (L to N), the effective short-circuit impedance of the network is obviously

$$\text{L.V. } Z_{sc}=Z_L+\left\{\frac{Z_H\times Z_N}{Z_H+Z_N}\right\}$$

$$=j60+\frac{(0.02+j120.1)^2}{2\,(0.02+j120.1)}$$

$$=-j60+0.01+j60.05$$

$$=(0.01+j0.05)\text{ ohms}$$

This is exactly the specified short-circuit impedance of the autotransformer, correct vectorially, as measured from the L.V. side. If the low-voltage side is short-circuited (L to N), and the high-voltage side is excited (H to N), we get,

$$\text{H.V. } Z_{sc}=0.02+j120.1+\frac{(0.02+j120.1)\,(-j60)}{0.02+j120.1-j60}$$

$$=(0.04+j\,0.20)\text{ ohms}$$

which again will be seen to be exactly the specified value for the autotransformer.

(*b*). Current ratio.

By inspection of the diagram, Fig. 2(c), under impedance test,

$$I_L=I_H\,\frac{(Y_H+Y_N)}{Y_H}=I_H\left(1+\frac{Y_N}{Y_H}\right)$$

$$=I_H\left(1+\frac{Z_H}{Z_N}\right)=I_H\left(\frac{Z_N+Z_H}{Z_N}\right)$$

But Z_H and Z_N are identical in the present case, and therefore,

$$I_L=2\,I_H$$

that is, the current in the low-voltage terminal L is twice that in the high-voltage terminal H.

Therefore, the network of Fig. 2(c) having the same no-load current and voltage-ratio characteristics and also the same short-circuit impedance and current-ratio characteristics as the autotransformer of Fig. 2(a), we conclude that they are "completely equivalent." To further verify this conclusion, we may test the full-load condition.

(3.) *Full-load Voltages*

Let us assume full-load at 80 per cent power-factor across the high-voltage winding. To maintain 2200 volts across this loaded high-voltage circuit, the impressed voltage across the low-voltage must be, by the Institute method,

$$E_{LV}=\frac{1100}{100}\left[100+0.8\times0.827+0.60\times4.13+\frac{(0.8\times4.13-0.6\times0.827)^2}{200}\right]=1135\text{ volts.}$$

To maintain 2200 volts across the loaded high-voltage leads of the equivalent network, we must impress across its low-voltage leads a voltage calculated as follows: Let the load impedance be designated by Z_O, with a numerical value of $4.84\,(0.8+j0.6)$ ohms. The following relations will be evident with the aid of Fig. 2(c).

$$E_{AN}=\left(\frac{Z_H+Z_O}{Z_O}\right)E_{HN}$$

$$E_{LN}=\frac{Z_L+\dfrac{(Z_H+Z_O)\,Z_N}{Z_H+Z_O+Z_N}}{\dfrac{(Z_H+Z_O)\,Z_N}{Z_H+Z_O+Z_N}}\times E_{AN}$$

$$=\frac{Z_L+\dfrac{(Z_H+Z_O)\,Z_N}{Z_H+Z_O+Z_N}}{\dfrac{(Z_H+Z_O)\,Z_N}{Z_H+Z_O+Z_N}}\times\frac{(Z_N+Z_O)}{Z_O}\,E_{HN}$$

$$=\frac{(Z_L+Z_N)\,(Z_H+Z_O)+Z_L\,Z_N}{Z_N\,Z_O}\,E_{HN}$$

Making numerical substitutions from Fig. 2(c), we find,

$$(Z_L+Z_N) = -j60+0.02+j120.1 = 0.02+j60.1$$

$$\begin{aligned}(Z_H+Z_O) &= 0.02+j120.1+4.84\ (0.8+j0.6)\\ &= 3.892+j123\end{aligned}$$

$$\text{Product} = -7{,}392.6+j236.37$$

$$Z_LZ_N = -j60\ (+0.02+j120.1) = -j1.20+7{,}206.$$

$$\begin{aligned}Z_NZ_O' &= (0.02+j120.1)\quad(3.872+j2.904)\\ &= -348.7+j465.1\end{aligned}$$

$$\begin{aligned}\therefore E_{LN} &= \left(\frac{-7{,}392.6+j236.37-j1.20+7{,}206}{-348.7+j465.1}\right)\times 2200\\ &= \frac{-186.6+j235.17}{-348.7+j465.1}\times 2200\\ &= \frac{174{,}444+j4{,}783.4}{337{,}900}\times 2200\\ &= (0.517+j0.014)\ 2200 \text{ vectorially}\\ &= 1136 \text{ volts numerically.}\end{aligned}$$

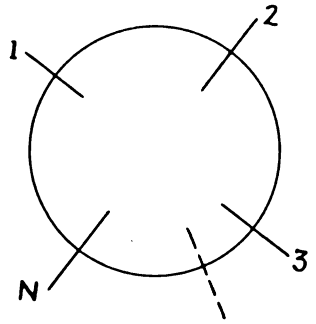

Fig. 3. Analogue in Which Electrical Circuit is Represented as Being Enclosed in a Sealed Vessel

This is seen to be the same as that of the autotransformer, within the accuracy of the numerical work.

Having thus shown the existence of a completely equivalent circuit in a concrete case for illustration, we now proceed to develop the theory more definitely, and to prove it mathematically for the general case.

Physical Considerations

Let Fig. 3 represent a sealed container enclosing an electrical circuit with n independent terminals, and no internal source of power. The electrical characteristics of the outfit at its terminals are determinable by measurements at those terminals without the necessity of knowledge of the internal construction.

Now all that can be measured across a pair of terminals is just *impedance!* And, therefore, a unity power-factor component may be represented by a resistance and a zero power-factor component by a reactance (with proper algebraic signs), regardless of the structure of the contents. Accordingly, a transformer or autotransformer should be completely represented by an impedance network. Considering broadly that a transformer or autotransformer is nothing but a specialized form of impedance, it becomes axiomatic that it should be completely representable by a suitable impedance network.

If one should object that a transformer or autotransformer functions by virtue of magnetic coupling among its circuits, but that no magnetic coupling is to be permitted along the links of the attempted equivalent impedance network, we may answer that the voltage transformation accomplished by magnetic coupling can be just as effectively accomplished by resonance, and the current transformation by shunts, as shown by the foregoing example.

In an outfit with n independent terminals, there will be $n\ (n-1)/2$ independent pairs of terminals and therefore the same number of independent impedances. The performance characteristics of the outfit within the closed container is therefore completely determined by this set of impedance values. But any set of $n\ (n-1)/2$ independent impedance values among n terminals can be completely satisfied by a network of n terminals with $n\ (n-1)/2$ independent links, and therefore the characteristics of an n-terminal outfit, which can be a transformer or an autotransformer, can be completely duplicated by an n-terminal network having $n\ (n-1)/2$ links.

For instance, Fig. 2(a) is a three-terminal outfit, and all that one can discover about it by means of measurements at its terminals is that certain impedance values exist among the terminals. There being only three independent terminals, there are only $n\ (n-1)/2$, or three, independent pairs of leads and the same number of independent impedances. But these terminal impedance characteristics can be completely satisfied by a three-terminal impedance network having three independent impedance links as in Fig. 2(c).

In general, the links in the equivalent impedance network may be arranged in any desired fashion, as star or mesh, or mixtures of the two, in any combination that may be found convenient, as long as the necessary number of independent links are provided; but, of course, the values of the links will also depend on their arrangement.

The considerations outlined above may now be formulated in the form of a theorem as follows:

Theorem

(*A*). For any given transformer or autotransformer, there exists an equivalent impedance network with the same performance characteristics, such as current and voltage transformation; efficiency; regulation; self, mutual, and leakage impedances; exciting currents and short-circuit currents.

(*B*). For any given impedance network, an equivalent transformer or autotransformer can always be specified.

Notes:

(1). The various branches of the impedance network are supposed to be absolutely independent, that is, with no magnetic coupling among themselves, because, to permit it would be to replace one transformer or autotransformer by another transformer or autotransformer.

(2). In the converse Theorem (*B*), though the transformer or autotransformer can always be specified, it does not necessarily follow that it can be built in every case.

(3). The equivalence may be true at only one frequency or at all frequencies, depending on how the links of the equivalent impedance network are chosen.

We must undertake now (*a*) to develop conversion formulas; and (*b*) to prove mathematically that the circuits so obtained are identical in all their performance characteristics.

Since the fewer the terminals the fewer are the links, and therefore the simpler is the problem, we shall first consider in detail three-terminal transformers and autotransformers. By a "three-terminal transformer," we mean one in which high and low-voltage neutrals are tied together, leaving only three leads per leg, that is, two line leads and one neutral lead per phase, or one in which one high-voltage lead, and one low-voltage lead are connected together.

Conversion Formulas for Transformers, Autotransformers and Impedance Networks with Three Independent Leads Per Phase.

The formulas for conversion from impedance networks to equivalent transformers or autotransformers are the more obvious and direct, and therefore we may consider them first.

(A). Conversion from an Impedance Network to Its Equivalent Autotransformer.

Given an impedance network in star with links Z_a, Z_b, Z_c as in Fig. 4(b). The corresponding equivalent autotransformer, Fig. 4(a), must have the following constants:

(1). Self-inductive or Exciting Impedances

By inspection of Figs. 4(a) and 4(b)

$$Z_{AB}=Z_{ab}=Z_a+Z_b \text{ vectorially,} \tag{1a}$$

$$Z_{BC}=Z_{bc}=Z_b+Z_c \text{ vectorially,} \tag{1b}$$

$$Z_{CA}=Z_{ca}=Z_c+Z_a \text{ vectorially,} \tag{1c}$$

Since the right-hand members of these equations (that is, the links of the impedance network) are assumed as given, the left-hand members (that is, the equivalent autotransformer characteristics) follow.

(2). Voltage-ratio at No Load

(*a*). With excitation on "*AB*" or "*ab*" (Figs. 4(a) and 4(b), no current flowing in branch *C* or *c*,

$$\frac{E_{AC}}{E_{AB}}=\frac{E_{ac}}{E_{ab}}=\frac{Z_a}{Z_a+Z_b} \tag{2}$$

(*b*) With excitation on "*AC*" or "*ac*" no current flowing in branch *B* or *b*,

$$\frac{E_{AB}}{E_{AC}}=\frac{E_{ab}}{E_{ac}}=\frac{Z_a}{Z_a+Z_c} \tag{3a}$$

$$\frac{E_{AC}}{E_{AB}}=\frac{E_{ac}}{E_{ab}}=\frac{Z_a+Z_c}{Z_a} \tag{3b}$$

The left-hand terms of Equations (2) and (3b) are identical, but not necessarily the right-hand terms; which means that the impedance network may have a different ratio when stepping-up than when stepping down. This of course, is also possible in transformers and autotransformers, occasionally to a troublesome degree.

(3) Current-ratio on Impedance Test

(*a*). With short-circuit on "*AC*" or "*ac*,"

$$\frac{I_B}{I_C}=\frac{I_b}{I_c}=\frac{Y_a+Y_c}{Y_c}=\frac{Z_a+Z_c}{Z_a} \text{ vectorially.} \tag{4}$$

(*b*). With short circuit on "*AB*" or "*ab*"

$$\frac{I_C}{I_B}=\frac{I_c}{I_b}=\frac{Y_a+Y_b}{Y_b}=\frac{Z_a+Z_b}{Z_a} \text{ vectorially.} \tag{5a}$$

(4). Leakage Impedance.

(*a*). *AB* excited—*AC* short-circuited—

$$Z_{(AB)\,(AC)}=Z_b+\left(\frac{Z_a\times Z_c}{Z_a+Z_c}\right) \text{ vectorially.} \tag{6}$$

(*b*). *AC* excited, *AB* short-circuited,

$$Z_{(AC)\,(AB)}=Z_c+\frac{Z_a\times Z_b}{Z_a+Z_b} \text{ vectorially.} \tag{7}$$

Equations like (1) to (7) can obviously be also written for circuit *BC* and *AB*, or *BC* and *AC*.

The many quantities defined by these formulas are not all independent, of course. A minimum of one magnetizing impedance, one leakage impedance, and one ratio would be necessary and sufficient (and also most convenient) in the simplest case.

(B). Conversion from an Autotransformer to Its Equivalent Impedance Network

Given a three-terminal autotransformer with self-inductive or exciting-current impedances Z_{AB}, Z_{BC}, and Z_{CA}, Fig. 4(a). The impedance links of the equivalent network, Fig. 4(b), must obviously satisfy Equations (1a), (1b), (1c). Therefore, solving these equations for Z_a, Z_b, and Z_c in terms of Z_{AB}, Z_{BC}, and Z_{CA}, we get,

$$Z_a = \frac{Z_{AB} - Z_{BC} + Z_{CA}}{2} \text{ vectorially.} \qquad (8a)$$

$$Z_b = \frac{Z_{BC} - Z_{CA} + Z_{AB}}{2} \text{ vectorially.} \qquad (8b)$$

$$Z_c = \frac{Z_{CA} - Z_{AB} + Z_{BC}}{2} \text{ vectorially.} \qquad (8c)$$

The superficial resemblance of these conversion formulas to those used in three-circuit transformers (3) must not be allowed to conceal the fundamental difference in the two schemes and their results, particularly in that one accomplishes current and voltage transformation while the other does not. Furthermore, there are differences in the basic data and the operations performed on them.

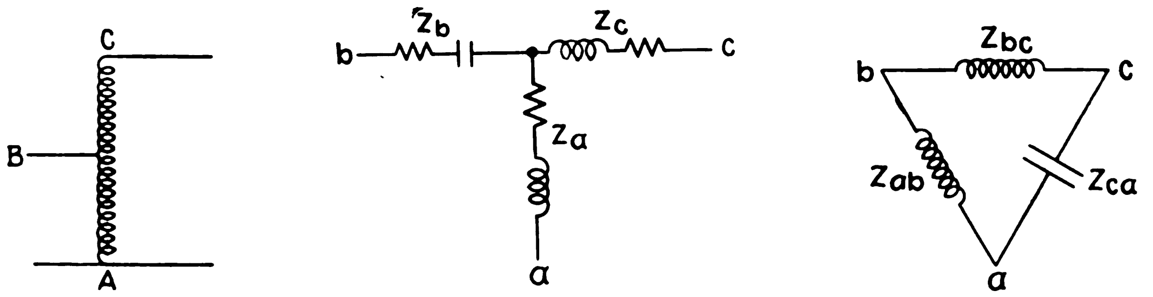

Fig. 4(a) Fig. 4(b) Fig. 4(c)

Fig. 4. Transformer Diagrams for Impedance Calculations

Fig. 4(a). Autotransformer. Fig. 4(b). Impedance network, star-connected.
Fig. 4(c). Equivalent network, delta-connected.

Thus:

(*a*). In three-circuit transformers the basic impedances refer to the leakage-impedances, while here they refer to the excitation impedances. (4)

(*b*). In three-circuit transformers, if the basic impedances are in ohmic values, they must be "reduced to a common basis" by multiplying them by the square of their respective turn-ratios to that "common basis," while here the actual ohmic values are used without any reduction.

(*c*). In three-circuit transformers, if the impedances are in percentage form, they must be based on a common kv-a. basis and their own respective currents and voltages; whereas in the present case, all percentages must be based on the same amperes and the same volts in order that the percentage impedances may have the same ratios as the actual ohmic values.

(*d*). Finally, the problems and purposes to which the two contrasting methods apply are usually very different from each other.

Equations (8a), (8b), (8c) are obviously completely adequate for determining the equivalent impedance network. They are also very simple and convenient so far as the calculation of the equivalent circuit for correct ratio of transformation is concerned. However, as far as making the equivalent circuit represent correctly the leakage impedance also is concerned, these equations are not very convenient, because the leakage impedance enters into the equations indirectly by its minute effect on the primary and secondary exciting impedances. Greater accuracy and convenience is therefore obtainable in general by using equations which take the leakage impedance into account explicitly instead of implicitly, as follows:

Let k be the ratio of transformation, low-voltage line voltage divided by high-voltage line voltage, and Z_{AC} the excitation impedance of the high-voltage or full windings.

Ignoring, for the moment, the leakage impedance, the excitation impedances across the other terminals will be:

$$Z_{AB} = k^2 \, Z_{AC}$$

$$Z_{BC} = (1-k)^2 \, Z_{AC}$$

and, from these, the links of the equivalent network will be:

$$Z_a = k \, Z_{AC} \qquad (9a)$$

$$Z_b = -k \, (1-k) \, Z_{AC} \qquad (9b)$$

$$Z_c = (1-k) \, Z_{AC} \qquad (9c)$$

This equivalent network will have perfect current and voltage transformation, with correct exciting current, but with zero leakage-impedance and zero losses. (Table I was prepared with the aid of these equations, so as to give an idea of how the impedance links vary in the equivalent circuit of an ideal autotransformer for various transformation ratios.)

Leakage-impedance may now be added to these equations of the equivalent network. If the relative effect of leakage-impedance on the exciting-current of the different circuits is unknown (which effect ordinarily is too small to be properly distinguished and is unimportant), we may apportion the per cent leakage reactance equally between the series and common windings, in which case, assuming the leakage impedance measured at the high-voltage terminals to be $Z_{(AC)\ (AB)}$ ohms, the preceding equivalent-circuit Equations (9a), (9b), (9c) completed so as to include leakage impedance also, become

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(3) See paper by the author on "Theory of Three-circuit Transformers," *Journal of the A.I.E.E.*, April, 1924, pp. 345 to 355.

(4) This distinction to be qualified later for delta representation.

$$Z_a = k\, Z_{AC} \left\{ \frac{k}{(l-k)} \right\}^2 \times \frac{Z_{(AC)\ (AB)}}{2} \qquad (10a)$$

$$Z_b = -k\ (l-k) Z_{AC} \qquad (10b)$$

$$Z_c = (l-k)\ Z_{AC} + \frac{Z_{(AC)\ (AB)}}{2} \qquad (10c)$$

Equations (10a), (10b), (10c) are more convenient and may sometimes yield greater accuracy than Equations (8a), (8b), (8c), in spite of the fact that the latter are mathematically exact.

Mathematical Proof of Equivalence

To establish mathematically the complete equivalence of the transformer or autotransformer and the corresponding equivalent impedance network obtained by the foregoing conversion formulas, it will be necessary and sufficient to prove that the primary and secondary circuits have the same self and mutual impedances in both outfits, because all transformer characteristics are completely determinable in terms of these constants.

That the equivalent impedance network Fig. 4(b) completely duplicates the self-inductive impedances of the autotransformer, Fig. 4(a), has already been shown in the derivation of the conversion formulas, Equations (1a), (1b), (1c) and (8a), (8b), (8c).

All that is necessary to prove now is the equality of the mutual impedances of the corresponding pairs of circuits in the autotransformer and the equivalent impedance network.

In the impedance network of Fig. 4(b), the mutual or common impedance between circuits "*ab*" and "*ac*" is obviously Z_a; that between circuits "*ab*" and "*bc*" is Z_b, and that between circuits "*ac*" and "*bc*" is Z_c; and we must therefore show that the mutual impedances between the circuits of the autotransformer, Fig. 4(a), are identically equal to these.

It might appear to one that the autotransformer of Fig. 4(a) has three independent self-impedances and three independent mutual impedances, altogether six independent constants. It will be shown now, however, that the three mutual impedances follow from the three self-impedances and are therefore not independent.

Assume that voltage E_{AC} is impressed across A–C to maintain one ampere, and that voltages E_{AB} and E_{BC}^{BC} are measured across A–B and B–C, respectively. Obviously,

$$E_{AC} = E_{AB} + E_{BC} \quad \text{vectorially.}$$

Since, however, the current is one ampere,

$E_{AC} = Z_{AC}$, self-impedance of AC.

$E_{AB} = M_{AC \text{ to } AB}$ mutual-impedance of AC to AB.

$E_{BC} = M_{AC \text{ to } BC}$ mutual impedance of AC to BC.

Making these substitutions in the foregoing equation for E_{AC},

$$Z_{AC} = M_{AC \text{ to } BC} + M_{AC \text{ to } BC}$$

$$\text{Similarly } Z_{AB} = M_{AB \text{ to } AC} + M_{AB \text{ to } BC}$$

$$Z_{BC} = M_{BC \text{ to } AC} + M_{BC \text{ to } AB}$$

Remembering that M_{xy} is the same as M_{yx}, and solving the preceding equation for the three mutual impedances involved and comparing the results with Equations (8a), (8b), (8c), we find,

$$M_{AB\ \&\ AC} = (Z_{AB} + Z_{AC} - Z_{BC})/2 = Z_a$$

$$M_{AB\ \&\ BC} = (Z_{AB} + Z_{BC} - Z_{AC})/2 = Z_b$$

$$M_{AC\ \&\ BC} = (Z_{AC} + Z_{BC} - Z_{AB})/2 = Z_c$$

Hence, the impedance network of Fig. 4(b) having the same self-impedances and the same mutual-impedances as the autotransformer of Fig. 4(a), the two are completely equivalent to each other.

TABLE I

Refer to Figs. 4(a) and 4(b)

Ratio $\frac{E_{AB}}{E_{CA}}$	Z_a	Z_b	Z_c
0.00	0	0	100
0.10	10	− 9	90
0.20	20	−16	80
0.25	25	−18.75	75
0.333	33.3	−22.2	66.6
0.50	50	−25	50
0.666	66.6	−22.2	33.3
0.75	75	−18.75	25
0.80	80	−16	20
0.90	90	− 9	10
0.99	99	− 0.99	1
1.00	100	0	0

The theorem is thus proved for three-terminal outfits, and can be extended to *n*-terminal cases; showing that the mutual impedances can be expressed in terms of the self-impedances, and that when the self-impedances are duplicated the mutual impedances are automatically duplicated.

Considering the theorem proved, we may now answer a number of related questions.

(1). Is the equivalence, formulated in the foregoing, true at all frequencies?

Not necessarily, but it is capable of being so. If the impedances are specified and duplicated at one frequency, the complete equivalence is true only at that frequency without any assurance for other frequencies. But if the impedances of one outfit are specified for various frequencies, and duplicated in the other outfit at all those frequencies, then the equivalence is true at all those frequencies. More comprehensively,

If the corresponding circuits of two outfits have the same characteristic impedance or admittance for a rectangular voltage, the two outfits are completely equivalent at all frequencies and for all transients.

This theorem follows from the Duhamel-Carson integral formula which definies the characteristics of a circuit for any wave-shape in terms of its characteristics for a unit rectangular voltage.

It may appear that if we had defined the constants of one of the outfits in terms of resistance, inductance, and capacitance, instead of specifying them in terms of impedance, and if those values were reproduced in the second outfit, we would have complete equivalence at all frequencies. This, however, is not possible. A circuit can not in general be defined as having so much resistance and so much inductance or capacitance. The simplest complete specification of a circuit would be its characteristic impedance or admittance (that is, its current *vs.* time curve) for a unit rectangular voltage.

(2). What is the significance of negative impedance links in the equivalent network?

A negative reactance of course means capacitive reactance, and involves nothing mysterious. If the question is asked how an inductive winding can yield a capacitance characteristic, the answer is that an autotransformer boosts the voltage (ordinarily we say "steps-up" the voltage) with a lagging magnetizing current flowing through it. But this is also the characteristic of a capacitor, to boost the voltage when a lagging current is passing through it. Although the mechanism of voltage-boost is totally different in the two cases, yet to reproduce the voltage-boosting characteristic of an autotransformer by means of a network of impedance links, we must take recourse to capacitors and inductors, that is, we must resort to resonance.

The equivalent network may also happen to have negative resistance. In a three-branch network, this can exist ordinarily in only one branch and that, again, the smallest kv-a. branch. The occurrence of an appreciable negative resistance branch is almost invariably due to core loss. The logic of this phenomenon might be stated as follows: In a network duplicating the excitation characteristics of a transformer or autotransformer, the ratio of resistance to reactance in each branch must be the same as the ratio of core loss component to the magnetizing current component. But, the no-load or exciting reactances of the transformer or autotransformer lead to a negative reactance branch or branches in the equivalent network as explained above, and therefore a branch with a negative reactance must also have a negative resistance to duplicate the ratio of core loss to magnetizing current with correct algebraic sign. To state the reasoning in still another way: since the exciting impedance of an autotransformer is a reactance plus a resistance, and since, in order to obtain the voltage boosting characteristic, the reactance has to be represented with a negative branch so that the voltage can be boosted by the lagging component of the exciting current, so also the exciting resistance has to be represented by a negative branch, so that the voltage may be boosted through it by the in-phase component of the exciting current. Negative resistance characteristics are shown by series generators and by vacuum tube outfits, etc. However, it is not really necessary to fetch them into the present discussion, as our primary interest now is the development of some concepts. For those who may have an aversion to the concept of negative resistance, we may say that so far as the functioning of a transformer or an autotransformer is concerned, core loss is not a necessary essential but a small accidental impediment. If core loss could be omitted in manufacture, as it can be omitted in calculation, transformers would perform so much the better. Therefore, since it is not only possible but very much easier to omit the core loss in the equivalent impedance network, it follows that the equivalent network can be made even better than the transformer or autotransformer, like a photograph flattering the subject by the retouching of a small blemish.

(3.) Why is the equivalent transformer or autotransformer not necessarily possible to build?

In the conversion of a transformer or autotransformer into an equivalent impedance-network, no physical difficulties are involved other than that of a negative resistance branch, which was shown to be unnecessary for the successful functioning of the outfit; but in the conversion of an impedance-network into a transformer or autotransformer, we may easily encounter physical impossibilities. For instance, referring to Fig. 4(b), if two of the impedance branches were negative, the equivalent transformer or autotransformer would have to have a leading exciting current! In a practical problem, if it is satisfactory to duplicate only the scalar characteristics and the algebraic signs are not essential, the signs of all the reactance links may be reversed and the equivalent transformer or autotransformer determined. But if the algebraic signs are insisted upon, a capacitance is of course unobtainable magnetically; and recourse has to be taken to capacitances of some form, perhaps to the capacitance between turns which in the higher voltage and particularly in the higher frequency transformers may render the no-load current leading instead of lagging. However, since the primary object of the present treatment is only an exposition of theoretical principles and not actually to replace transformers or autotransformers by impedance networks in the industry, nor impedance networks by transformers or autotransformers, it is not necessary to dwell here on how to make the no-load current of a transformer or autotransformer leading any more than on how to obtain negative resistance. It is very desirable to note, however, that impedance networks are more general and have greater freedom in characteristics than transformers or autotransformers, and that, therefore, while the main useful characteristics and the majority of the incidental characteristics of transformers and autotransformers can be exactly duplicated by impedance networks, not all impedance networks can necessarily be duplicated by transformers or autotransformers if the algebraic signs and not merely the scalar values of the characteristics are insisted upon.

(4). How about saturation phenomena?

Although saturation is one of the tertiary (not even secondary) incidental characteristics of a transformer or autotransformer and may well be ignored, yet, in order to guard against the possible assumption that it may vitiate the foregoing theorem of equivalence, we may add that the saturation characteristics of the transformer may be duplicated by the equivalent network assuming that the links of the equivalent network also have corresponding saturation characteristics. So far as harmonics are concerned, diagrammatic schemes are already known to represent their characteristics in various circuits, but it does not appear desirable that the equivalent network, representing the fundamental characteristics, be complicated by the addition of these features. So far as satisfaction of theoretical generality is concerned, suitable saturation of the links in the equivalent network would reproduce the desired harmonics.

(5). If the primary and secondary of a transformer are completely insulated from each other, with no metallic connection between them, how is the equivalent impedance network to represent it?

In this case, the transformer has four independent terminals per phase, involving six pairs of leads, and hence, six independent impedances of which two will normally be lagging and four leading.

The leading impedances will appear when one primary and one secondary lead are paired. The problem is thus perfectly determinate, even though laborious, by requiring the solution of six complicated simultaneous equations. A practical procedure would be to assume that the primary and secondary neutrals are joined through an impedance Z_n, and, after the problem is solved, to assign Z_n any desired value, for instance, infinity. Any connection with six independent links may be used for the impedance network. One will note by trial that in going from a three-terminal outfit to a four-terminal outfit, the complications of the problem are increased many fold, and therefore, unless really necessary, the primary and secondary should not be assumed completely insulated from each other, but joined together at the neutral for three-phase and at one end for single-phase cases, to simplify the work.

Choice of Connections: Y and Delta Formulas

For three-terminal cases, two alternative connections are obvious, namely, the star and the mesh (or, Y and delta, in appearance, though actually single-phase). For general purposes, the star connection of the impedance network is preferable and was used in the foregoing for the exposition of the theory. For certain particular purposes, however, the mesh or delta arrangement may prove more advantageous. For instance, if in a network problem, it is desired to ignore the exciting current completely, and determine the effect of leakage impedances alone, the mesh or delta connection of the impedance network appears desirable.⁽⁵⁾

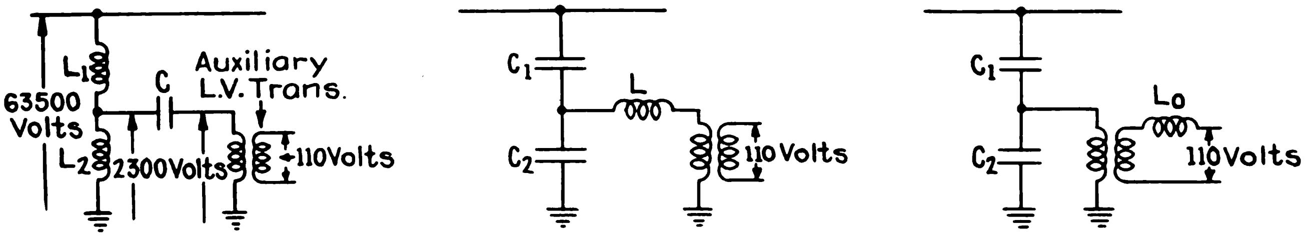

Fig. 5(a) Fig. 5(b) Fig. 5(c)

Fig. 5. Diagrams for a Step-down Autotransformer

Fig. 5(a). Impedance network, showing voltage at no load. Fig. 5(b). Network of 5(a) with positive and negative impedance interchanged. Fig. 5(c). Impedance network in which inductor is placed in low-voltage side of auxiliary transformer.

For convenience in reference, we may tabulate here the conversion formulas for both the Y and the delta equivalent network.

Let Z_o = Open-circuit impedance in ohms across the H.V. terminals of the autotransformer (AC excited, AB open, Fig. 4(a)).

Z_s = Short-circuit impedance in ohms across the H.V. terminals of the autotransformer (AC excited, AB short-circuited, Fig. 4(a)).

$k = E_{AB} / E_{AC}$, Fig. 4(a).

Case I: For the equivalent Y, Fig. 4(b), ignoring the leakage impedance, but considering the exciting impedance,

$$Z_a = k\ Z_o$$
$$Z_b = -K\ (1-k)\ Z_o$$
$$Z_c = (1-k)\ Z_o$$

Case II: For the equivalent delta, Fig. 4(c), ignoring the exciting current, but considering the leakage impedance,

$$Z_{ab} = \frac{k^2}{(1-k)} Z_s$$
$$Z_{bc} = K\ Z_s$$
$$Z_{ca} = \frac{-k}{(1-k)} Z_s$$

---

(5) This advantage of the delta connection was called to the attention of the writer by D. R. MacLeod.

Practical problems are likely to fall under either Case I or Case II, making it possible to use these simplified formulas.

Economic Considerations

In general, it is very uneconomical to physically replace a transformer or autotransformer by an equivalent impedance network, because the kv-a. rating of the latter would be many times the output of the transformer or autotransformer. This may become evident on considering that the impedance links of the equivalent Y network are of the order of the magnetizing impedance of the transformer or autotransformer and have to carry the full-load current; while those of the delta network, though of the order of the leakage impedance of the transformer, have to stand the line voltage. Thus, the I^2Z of the links of the equivalent impedance network may be from 10 to 100 or more times the kv-a. rating of the tranformer or autotransformer. In the case of the 1000-kv-a. autotransformer considered the high-voltage link of the equivalent Y impedance network would be, in round numbers, 25,000 kv-a.; low-voltage link 50,000 kv-a.; and the neutral link 25,000 kv-a. The kv-a. ratings of the links of the equivalent delta network will be of the order of the full-voltage short-circuit kv-a. of the autotransformer.

In exceptional cases, however, the kv-a. ratings involved may not be really indicative of cost, as for instance in the case of so-called capacitance transformers or dividers intended for drawing a minute fraction of a kv-a. from a very high voltage circuit. Such a circuit is obtained as follows: By Theorem (A), the necessary step-down autotransformer is converted into an impedance network as shown in Fig. 5(a), and the load is introduced through an auxiliary low-voltage potential transformer. Changing the positive reactances of the network into negative, and the negative reactances into positive, we obtain the network shown in Fig. 5(b). If desired, the inductor L may be transferred to the low-voltage side of the auxiliary potential transformer Fig. 5(c) or replaced altogether by sufficient inherent reactance in the auxiliary potential transformer itself. For sufficiently small loads on sufficiently high voltage circuits, the scheme of Fig. 5(c) may show an economy over a straight high-voltage potential transformer.

Electric Lines Now Serve Almost Every Community in the United States

One of the notable features in the development of electric service during the past five years is its rapid spread to small communities and villages. Information recently compiled by the National Electric Light Association shows that more than 4000 towns and villages have been reached for the first time with electricity, since 1923, an increase of 26 per cent. What is even more interesting is the fact that they are receiving the same high-quality 24-hr. service formerly enjoyed by only the large cities. Every city and town in the United States with a population of 5000 or more; 97 per cent of communities with populations of 1000 to 5000; over 50 per cent of communities with between 250 and 1000 populations; and 25 per cent of all hamlets with less than 250 population are now reached by the copper wires of the light and power companies.

An important contributing factor to this spread of electric service is the rapid growth of interconnection. Without interconnection, thousands of these communities would either be without any service or would have it for only a few hours at best.

The transmission lines of an interconnected system form a network covering a considerable amount of territory. The result is that continuous 24-hr. service, the same service that is being received by the large cities in the territory, is available to small villages and hamlets and is rapidly extending to the farming districts. Many of these small communities could not support a local plant. The investment requirements for such a plant would be entirely too great for the small amount of business it would receive. The rates would be so high that few could possibly afford the service.

Interconnection also makes possible the decentralization of industry. From a power standpoint the small town has equal opportunity with the large city. Decentralization of industry is bound to benefit the farmer by creating close-by markets for many of his products.

Again, interconnection gives the small community fuller protection against interruption of service. When the isolated power plant shuts down because of storms, water shortage, failure of transportation, or failure of equipment, all electric service ceases. There are no reserves to call upon. Power supplied over interconnected systems is rigorously safeguarded, plants and transmissions of the whole system coöperate in maintaining continuity of service.

Interconnection has been largely responsible for the enormous increase in the use of electricity in the United States, which is expanding faster than the population increases. The amount generated has increased 626 per cent during the past 15 years; the number of customers has increased 465 per cent; population living in electrically-wired homes 520 per cent; whereas population has increased but 24 per cent.

New Equivalent Circuits for Autotransformers and Transformers with Tapped Secondaries

With Some Examples of Their Use in Analyzing Single-phase Three-wire A-c. Railway Systems

By D. R. MacLeod
Railway Engineering Department, General Electric Company

THE representation of electrical machines by simple combinations of resistance and reactance has long been known. The usual method is to represent the machine, and the circuit to which it is connected, by a circuit in which the terminals of the equivalent machine are *not identical* with those in the actual machine. For example, the transformer shown in Fig. 1 is commonly represented by the simple combination of resistance and reactance as shown in Fig. 1(a). The terminal *E* in Fig. 1(a) is equivalent to the two terminals *A* and *B* in Fig. 1 since it represents one side of the transformer; the terminal *F* is equivalent to terminals *C* and *D* since it represents the other side of the transformer. Equivalent circuits of this nature have been derived for autotransformers, three-winding transformers, and four-winding transformers; and they have been in use for a number of years.

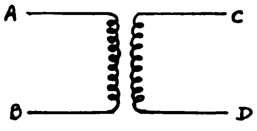

Fig. 1

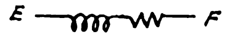

Fig. 1(a)

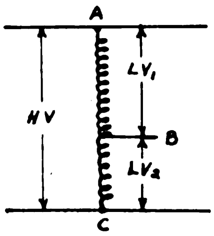

Fig. 2

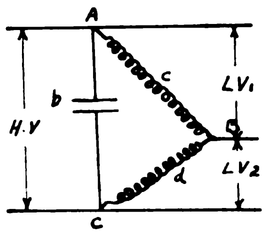

Fig. 2(a)

In diagrams of three-wire networks, it is often very desirable that the terminals of the equivalent circuit be the *same* as the terminals of the electrical machine that it represents. This is especially true in the case of three-wire a-c. railway systems in which we have many trains located at different points between stations. The equivalent circuits, which will be described in this article, were developed as an aid to a more accurate investigation of these systems than has heretofore been possible.

The few simple principles which were used in developing the equivalent delta circuits described in this article are given, but only sufficient proof of equivalence is offered to make the article complete in itself. The general theorems of equivalence underlying the new theory of transformers and autotransformers are described by A. Boyajian in a companion article(1) which should be referred to for a more general treatment of the subject and for rigorous proofs of the principles involved.

In all ordinary calculations of networks the magnetizing currents may be neglected without appreciable error, therefore the equivalent deltas are developed on the assumption that the magnetizing impedences of the corresponding machines are infinite.

The Autotransformer

In an autotransformer with a single tap, as shown in Fig. 2, three leakage reactances may be considered to exist.

(1). From the *HV* winding to the LV_1 portion of the winding.

(2). From the *HV* winding to the LV_2 portion of the winding.

(3). From the LV_1 portion of the winding to the LV_2 portion, or vice versa.

There is of course only one basic leakage reactance, the other two being related to it by the voltage ratios of the portions of the windings between which the leakage reactances are being considered.

If the equivalent circuit is to represent the autotransformer exactly insofar as terminal conditions are concerned, the following conditions must hold:

(1). The impedances between the various circuits on short circuit and under load must be the same as in the actual autotransformer.

(2). The ratio of the voltages of the various circuits must be the same on open circuit as it is in the actual autotransformer under the same condition. Under load, this ratio will vary on account of the impedance drops.

The combination of positive and negative impedances shown in Fig. 2(a) fulfills these conditions exactly. It will be noted that the terminals in Fig. 2(a) correspond with those in Fig. 2. The fundamental condition that must exist is that the sum of the two positive impedances $(c+d)$ must be equal to the negative impedance (b). Furthermore, the arithmetic ratio of the three impedances must be the same as the arithmetic ratio of the corresponding voltages across the three terminals of the autotransformer. The reasons for these statements and the exactness of the equivalent circuit can best be shown by developing the formulas for the equivalent circuit of an autotransformer having a ratio m.

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(1) See "New Theory of Transformer and Autotransformer Circuits," by A. Boyajian, on page 110 of this issue.

In Fig. 3 an autotransformer is shown which has a no-load voltage ratio m. The three voltages are:

(1). Between terminals A and $C = mV\ KV$.

(2). Between terminals B and $C = V\ KV$.

(3). Between terminals A and $B = (m-1)\ V\ KV$.

Let the impedance offered by the autotransformer between the $mV\ KV$. circuit and the $V\ KV$. circuit be x per cent on the rated kv-a. base. The other impedances on the same kv-a. base are:

$$(m-1)V \text{ KV. to } V \text{ KV.} = \left[\frac{m}{m-1}\right]^2 x \text{ per cent}$$

$$mV \text{ KV. to } (m-1)\ V \text{ KV.} = \frac{x}{(m-1)^2} \text{ per cent}$$

Since the impedances of the lines to which these autotransformers are connected are calculated in ohms and since in the particular problem for which these circuits were developed it was more convenient to work in ohms, the formulas will be developed with the constants of the autotransformers expressed in ohms.

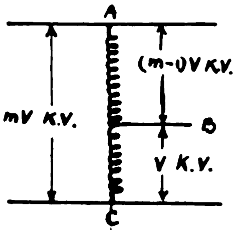

Fig. 3

The mV KV. to V KV. impedance expressed in ohms connected to the mV KV. line is:

$$\text{Impedance } mV \text{ to } V \text{ KV.} = \frac{x \times 10 \times (mV)^2}{\text{kv-a.}} \text{ ohms}$$

$$= m^2 Kx \text{ ohms (referred to } mV \text{ KV.)}$$

$$\text{where } K = \frac{10\ V^2}{\text{kv-a.}}$$

Similarly

$$\text{Impedance } mV \text{ to } (m-1)\ V \text{ KV.} = \left[\frac{m}{m-1}\right]^2 Kx \text{ ohms}$$

(referred to mV KV.)

$$\text{Impedance } (m-1)\ V \text{ to } V \text{ KV.} = m^2\ Kx \text{ ohms}$$

(referred to $(m-1)\ V$ KV.)

The impedances of a transformer or an autotransformer are determined on test by short circuiting one winding and applying voltage to the other winding. The values of b, c, and d in the equivalent circuit, Fig. 3(a), will be determined in this way and then the results will be checked by considering an autotransformer with a load connected to it.

When the winding BC of the actual autotransformer, Fig. 3, is short circuited and voltage is applied to terminals A and C, the measured impedance will be m^2Kx since this is the impedance between the two circuits, referred to the mV KV. circuit. When BC of the equivalent circuit, Fig. 3(a), is short circuited and voltage is applied to AC, the measured impedance is $\frac{bc.}{b+c}$. Since the equivalent circuit must represent the autotransformer exactly,

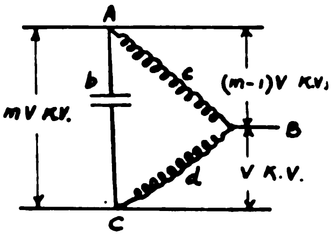

Fig. 3(a)

$$\frac{bc}{b+c} = m^2\ Kx \tag{1}$$

Similarly

$$\frac{bd}{b+d} = \left(\frac{m}{m-1}\right)^2 Kx \tag{2}$$

$$\frac{cd}{c+d} = Kx \tag{3}$$

where b, c, and d are the sides of the equivalent delta shown in Fig. 3(a).

Solving Equations (1), (2), and (3) simultaneously

$$b = -\frac{m^2}{m-1} Kx \tag{4}$$

$$c = mKx \tag{5}$$

$$d = \frac{m}{m-1} Kx \tag{6}$$

On open circuit the ratio of the voltage across AB to that across BC in the equivalent circuit, Fig. 3(a), must be the same as the ratio in the corresponding autotransformer, Fig. 3. On open circuit the current in AB is the same as that in BC since they are in series, therefore the impedance of AB must be to the impedance in BC in the ratio of the corresponding voltages. Since the ratio of the voltages across AB and BC in Fig. 3 is $(m-1)$ to 1, the impedance of c must be $(m-1)$ of the impedance of d. Equations (5) and (6) show that this is true. Similarly, the voltage ratios between the other windings may be shown to be the same on open circuit in the equivalent circuit as they are in the actual autotransformer.

Since we neglect the magnetizing current in all ordinary calculations, the equivalent circuit must offer infinite impedance on open circuit; *i.e.*, if we connect voltage across any two terminals of the equivalent circuit and leave the other open no current will flow. Referring to Fig. 3(a) assume that voltage is applied across AC, then the impedance

$$=\frac{b\,(c+d)}{b+c+d} \qquad (7)$$

Substituting Equations (4), (5), and (6) in (7)

Impedance $=\infty$

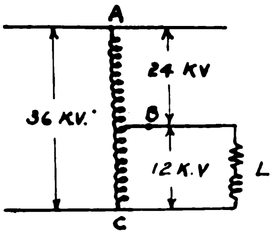

Fig. 4

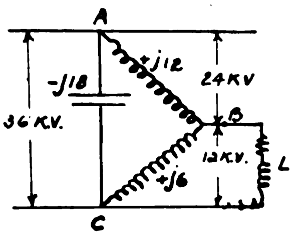

Fig. 4(a)

Therefore no current flows through the equivalent circuit on open circuit.

As a simple check on the equivalence of the circuit shown in Fig. 2(a) we will consider an actual autotransformer with a one-third tap which is to take power from a 36-kv. circuit and supply it to a load L at 12 kv. The actual autotransformer and its load are shown in Fig. 4. Fig. 4(a) shows the equivalent circuit. Let the reactance offered by the autotransformer between the 36-kv. and 12-kv. circuits be 4 per cent and let the rating of the autotransformer be 1440 kv-a.

In this case $m=3$

$$K=\frac{10\times 144}{1440}$$
$$=1$$
$$x=4$$

Substituting in Equations (4), (5), and (6)

$$b=-j18$$
$$c=+j12$$
$$d=+j6$$

The total impedance of the circuit referred to the 36-kv. side

$$=\frac{-j18\left[j12+\dfrac{j6L}{j6+L}\right]}{-j6+\dfrac{j6L}{j6+L}}$$
$$=j36+9L$$

The impedance from the 36-kv. to the 12-kv. circuit

$$=\frac{j4\times 10\times 36^2}{1440}$$
$$=j\,36 \text{ ohms}$$

Therefore, the total impedance for the autotransformer and load referred to the 36-kv. winding is $j\,36+9\,L$, which checks with the value found by using the equivalent delta.

Transformer with Tapped Secondary

If an ordinary two-winding transformer is tapped at some point in the secondary winding, the impedance between the primary and one portion of the secondary winding bears a certain relation to the impedance between the primary and the other portion of the secondary depending on the point in the secondary at which the tap is taken. The equivalent circuit which will be developed later applies to such a transformer. In order to make the application more general, however, a transformer will be considered in which the impedance between the primary and one portion of the secondary does not bear a fixed relation (depending on where the secondary is tapped) to the impedance between the primary and the other portion of the winding. In a transformer of this nature, Fig. 5, there are two only leakage impedances that are independent of each other. Six leakage impedances, however, may be considered. Referring to Fig. 5 these impedances are

(1). From AB to DF
(2). From AB to CD
(3). From AB to CF
(4). From CD to DF
(5). From CD to CF
(6). From DF to CF

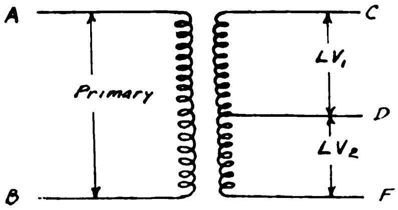

Fig. 5

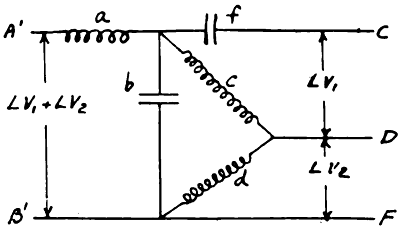

Fig. 5(a)

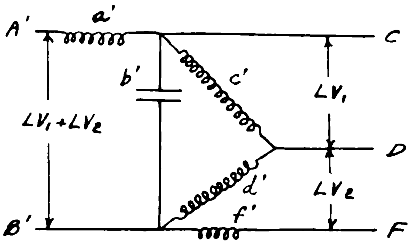

Fig. 5(b)

The equivalent circuit shown in Fig. 5(a) has been derived to represent the transformer shown in Fig. 5 exactly, insofar as terminal conditions are concerned. The equations and the values of the various positive and negative impedances forming the equivalent circuit will show that there are only two independent leakage impedances. The voltage across $A'B'$ in the equivalent circuit, Fig. 5(a), is not the same as the primary voltage AB in the actual transformer, Fig. 5, except in the case where the ratio of transformation is unity. Therefore, before calculating the equivalent circuit we must change the actual transformer to one with a ratio of transformation of unity. This does not introduce any particular difficulty since the current entering at A' and leaving at B' in the equivalent circuit will be related to the current in the actual transformer by the ratio of transformation.

The essential relations that must exist between the impedances in the equivalent circuit are:

(1). Impedances b, c, and d must be in the same arithmetic ratio as the voltages across CF, CD, and DF.

(2). The algebraic sum of b, c, and d must be zero.

(3). Impedance a must be equal to impedance b but opposite to it in sign.

(4). Impedance f may be positive or negative.

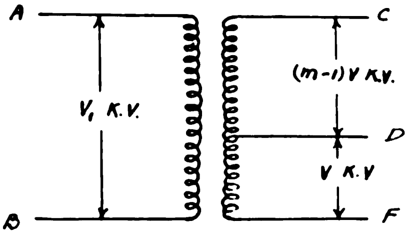

Fig. 6

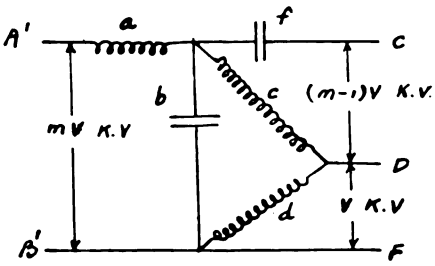

Fig. 6(a)

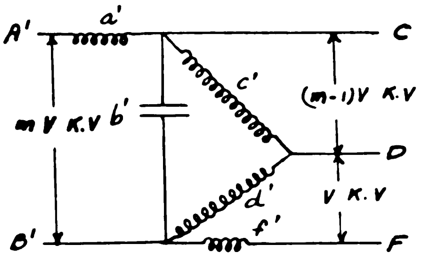

Fig. 6(b)

The formulas for determining the constants of the equivalent circuit of a transformer with a tapped secondary will be developed. In Fig. 6 a transformer is shown whose kilovolt rating is $V_1 - mV/(m-1)\ V/V$ kilovolts and whose impedances are

V_1 to V KV. $= y$ per cent (based on the transformer rating)

V_1 to $(m-1)V$ KV. $= x$ per cent (based on the transformer rating)

The other impedances based on the transformer rating are:

$$V_1 \text{ to } mV \text{ KV.} = \left[\left(\frac{m-1}{m}\right)^2 x + \frac{1}{m^2} y\right] \text{per cent}$$

$$(m-1)\ V \text{ to } V \text{ KV.} = (x+y) \text{ per cent}$$

$$mV \text{ to } V \text{ KV.} = \left(\frac{m-1}{m}\right)^2 (x+y) \text{ per cent}$$

$$mV \text{ to } (m-1)\ V \text{ KV.} = \frac{1}{m^2}(x+y) \text{ per cent}$$

Since the impedances of the lines connected to the transformer are usually calculated in ohms and since the other transformers or autotransformers may be of different rating, we will reduce the transformer impedances to ohms and determine the equivalent circuit accordingly. (Of course, the method of deriving the equivalent circuit would be the same if we elected to work with percentage values.)

The same general method which we used for obtaining the equations for the autotransformer will be used here. The impedances of the equivalent circuit are found by placing short circuits across terminals and measuring impedances between the other terminals just as if the equivalent transformer, Fig. 6(a), were under test.

The equations for determining the sides of the mesh are found to be

$$f + \frac{ab\ (c+d)}{(c+d)\ (a+b)\ +ab} = \frac{(mV)^2 \times 10}{\text{kv-a.}}\left[\left(\frac{m-1}{m}\right)^2 x + \frac{y}{m^2}\right] \tag{8}$$

$$f + \frac{cd\ (a+b) + abc}{(c+d)\ (a+b) + ab} = \frac{(m-1)^2 V^2 \times 10\ x}{\text{kv-a.}} \tag{9}$$

$$\frac{cd\ (a+b) + abd}{(c+d)\ (a+b) + ab} = \frac{V^2 \times 10\quad y}{\text{kv-a.}} \tag{10}$$

$$f + \frac{bc}{b+c} = \frac{(m-1)^2 V^2 \times 10\ (x+y)}{\text{kv-a.}} \tag{11}$$

$$\frac{bd\ (f+c) + fcd}{(f+c)\ (b+d) + fc} = \frac{(mV)^2 \times 10}{\text{kv-a.}} \times \frac{(x+y)}{m^2} \tag{12}$$

$$\frac{cd\ (b+f) + bfc}{(b+f)\ (c+d) + bf} = \frac{V^2 \times 10\ (m-1)^2}{\text{kv-a.}} \times \frac{(x+y)}{m^2} \tag{13}$$

The voltage drop from C to D, Fig. 6(a), must be $(m-1)$ times that from D to F when the transformer is open circuited. Under this condition the current in c is the same as the current in d, therefore

$$c = (m-1)d \tag{14}$$

Solving Equations (8) to (14) we obtain

$$\left.\begin{aligned} a &= +md &&= +mKy \\ b &= -md &&= -mKy \\ c &= +(m-1)d &&= +(m-1)Ky \\ d &= +d &&= +Ky \\ f &= &&= +(m-1)^2 Kx - (m-1)\ Ky \end{aligned}\right\} \tag{15}$$

$$\text{Where } K = \frac{10\ V^2}{\text{kv-a.}}$$

Since we neglect the magnetizing current taken by a transformer in all ordinary calculations, the equivalent circuit should offer infinite impedance on open circuit. Referring to Fig. 6(a) and considering the results given in Equation (15), we see that this condition is met since

$$b+c+d=0 \tag{16}$$

As a simple check on the equivalence of the circuit shown in Fig. 5(a) we will consider a 7200-kv-a. transformer, Fig. 7, whose primary voltage is 13.2 kv. and whose secondary voltages are 36/24/12 kv. The reactances are

13.2 − 24 kv. = 6.25 per cent
13.2 − 12 kv. = 20.00 per cent
13.2 − 36 kv. = 5.00 per cent

In this case

$$m=3$$

$$K=\frac{1440}{7200}=0.2$$

$$x=6.25$$

$$y=20.00$$

Substituting in Equation (15)

$$\left.\begin{aligned} a&=j12\\ b&=-j12\\ c&=j8\\ d&=j4\\ f&=-j3 \end{aligned}\right\} \tag{17}$$

The resistances of the transformer would be treated in the same way but for the sake of simplicity they are neglected in this problem. The equivalent circuit is shown in Fig. 7(a). The impedance of the load and transformer referred to the terminals A' and B' is

$$Z_{ll}=a+\frac{b(f+L_1)\ (c+d)+bcd}{(f+L_1)\ (b+c+d)+c\ (b+d)} \tag{18}$$

Substituting Equation (17) in (18)

$$Z_{ll}=(j11.25+2.25\ L_1) \tag{19}$$

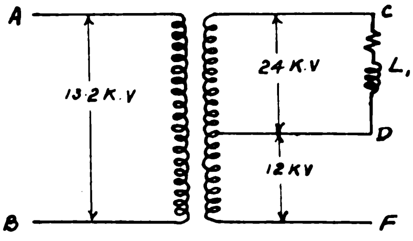

Fig. 7

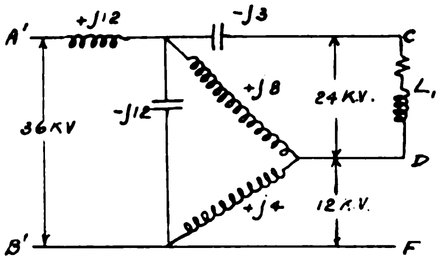

Fig. 7(a)

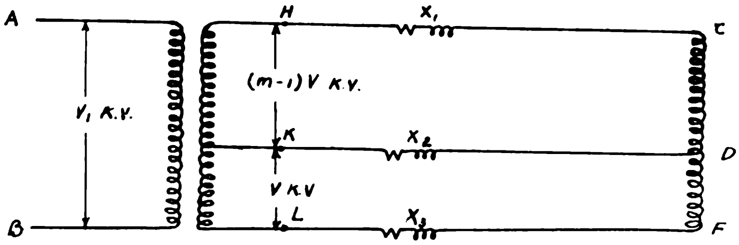

Fig. 8

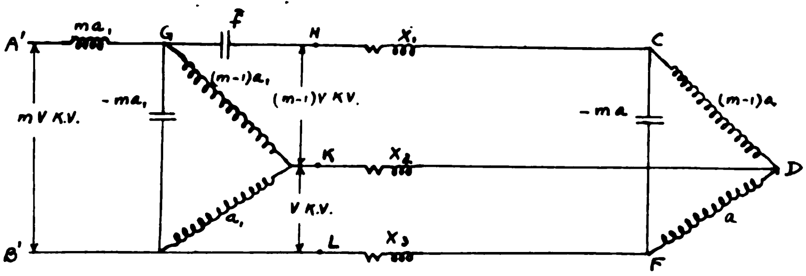

Fig. 8(a)

The impedance from the 13.2-kv. to the 24-kv. circuits equals 6.25 per cent which is $j11.25$ ohms referred to 36 kv. The load L_1 connected across the 24-kv. terminals referred to the 36-kv. base is $\frac{9}{4}L_1$. Therefore, the total impedance is $j11.25+\frac{9}{4}L_1$ referred to a 36-kv. base. This result checks with Equation (19).

Other tests may be made and it will be found that the circuit is exactly equivalent to a transformer if magnetizing current and saturation are neglected.

The equivalent circuit for a transformer with a tapped secondary might have been developed in a different form. Fig. 5(b) shows another circuit that is equivalent to the transformer shown in Fig. 5. The only difference is that in Fig. 5(b) f' is placed in lead F instead of in lead C as in Fig. 5(a). The constants for this circuit are derived in the same manner as for Fig. 5(a) and are found to be

$$\left.\begin{aligned} a' &= m(m-1)\,Kx \\ b' &= -m(m-1)\,Kx \\ c' &= (m-1)^2\,Kx \\ d' &= (m-1)\,Kx \\ f' &= Ky-(m-1)\,Kx \end{aligned}\right\} \quad (20)$$

This circuit is shown in Fig. 6(b).

It will be noticed that f in Fig. 6(a) is opposite in sign and $(m-1)$ times as great as f' in Fig. 6(b). The constants a, b, c, and d in Fig. 6(a) take their values from the V_1 KV. to V KV. impedance whereas a', b', c', and d' in Fig. 6(b) take their values from the V_1 KV. to $(m-1)$ V KV. impedance.

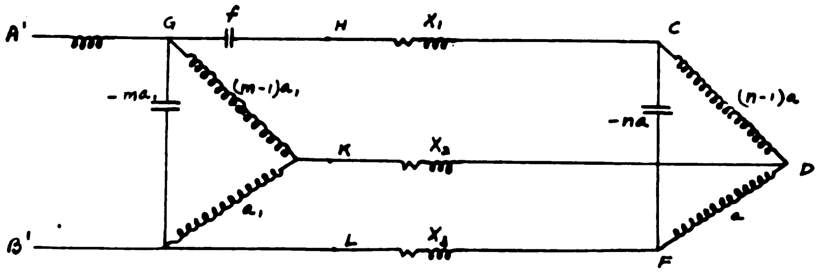

Fig. 8(b)

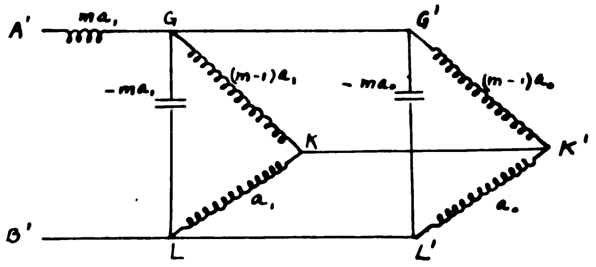

Fig. 8(c)

Relation Between Transformer with Tapped Secondary and Simple Autotransformer.

A comparison of Figs. 5(a) and 5(b) with Fig. 2(a) will immediately reveal the fact that the transformer in Fig. 5 may be considered as an ordinary two-winding transformer whose secondary supplies an autotransformer, which, in turn, supplies the external circuit through a capacitor or an inductive reactor, depending on the relative values of the impedances of the actual transformer and the line in which the equivalent external reactance is assumed to be connected. Thus the transformer in Fig. 5 may be analyzed in two ways.

(1). Where the capacitor or reactor in the equivalent circuit is connected in lead C as in Fig. 5(a).

(2). Where the capacitor or reactor in the equivalent circuit is connected in lead F as in Fig. 5(b).

If the impedance from the V_1 KV. to V KV. circuits is $(m-1)$ times the impedance from the V_1 KV. to $(m-1)$ V KV. circuits, i.e., if $y=(m-1)x$, the Equations (15) and (20) become identical and f and f' both become zero. Any other ratio of these impedances is therefore equivalent to connecting an external reactor or capacitor in one of the outer secondary leads of a transformer in which the ratio of the leakage impedances between the primary and each of the two parts of the secondary are in the inverse ratio of the voltages of the two parts. This fact is of great value when analyzing single-phase three-wire a-c. railway systems.

Some Simple Circuits

Fig. 8 shows the simplest possible system consisting of a transformer with a tapped secondary and an autotransformer. Fig. 8(a) shows the equivalent circuit. The impedances of the autotransformer and transformer are such that the sides of the equivalent circuits have the values a, $(m-1)a$, $-ma$, and a_1, $(m-1)a_1$, $-ma_1$, ma_1, and f as shown in the diagram. The lines are assumed to have impedances X_1, X_2, and X_3. X_1 and f may be lumped into a single impedance X'_1. By means of Y–delta transformations the circuit to the right of GKL may be collapsed into a delta the sides of which are

$$K'L'=a_0=a+\frac{X'_1}{m(m-1)}+\frac{m}{(m-1)}X_2+\frac{(m-1)}{m}X_3 \quad (21)$$

$$G'K'=(m-1)a_0$$

$$G'L'=-ma_0$$

Thus the circuit $GKLCDF$ is equivalent to an autotransformer having an impedance from the mV KV. to V KV. circuits

$$=m(m-1)a_0 \text{ ohms}$$

$$=m(m-1)a+X'_1+m^2X_2+(m-1)^2X_3 \text{ ohms}$$

The terminals of this equivalent autotransformer are $G'K'L'$ as shown in Fig. 8(b); the terminals

CDF of the actual autotransformer are completely isolated in the new equivalent autotransformer. If the sides of the delta $G'K'L'$ are paralleled with the corresponding sides of the delta GKL, a resonant delta having sides in the arithmetic ratio $1:(m-1):m$ is obtained. Therefore, only magnetizing current will flow in this circuit.

It sometimes happens that after a system is installed it is proposed to change the voltage ratio of some of the autotransformers in order to correct for telephone interference. If the tap D for the autotransformer in Fig. 8 had been taken so that the open-circuit ratio of the voltages when the autotransformer is isolated were $1:(n-1):n$ instead of $1:(m-1):m$, the equivalent circuit would be as shown in Fig. 8(c). The sides of the equivalent delta representing the circuit to the right of GKL would have the ratio $1:(n-1):n$ and would therefore form a resonant delta as before. When this delta is paralleled with the delta GKL, however, the resultant delta is not resonant. The kv-a. taken by the system is found to be

$$=\frac{m^2\,(m-n)^2\,V^2}{mn\,[n(m-1)a_1+m\,(n-1)\,a_0]}$$

The actual division of circulating current in the network may be found by an application of Kirchoff's laws. This artifice, therefore, results in a power loss which for small differences between m and n varies approximately as the square of this difference. In general, however, the artifice should be used only as a last resort.

Fig. 9 shows a simple network in which there is a main transformer with a secondary supplying power to a system at the end of which an autotransformer is placed to boost the voltage; a load L_1 is located between the two stations. Fig. 9(a) shows the equivalent circuit. The sides of the equivalent delta for the circuit to the left of GKL are

$$\left.\begin{aligned} b&=\frac{N}{-(m-1)\,L_1+X_4}\\ c&=\frac{N}{mL_1+X_5}\\ d&=\frac{N}{m(m-1)\,(a_0+L_1)}\end{aligned}\right\}\qquad(22)$$

where $N=[X_4-(m-1)L_1]\;[X_5+mL_1]$
$+m(m-1)(a_0+L_1)(X_4+X_5+L_1)$

and $a_0=a+\dfrac{X'_1}{m(m-1)}+\dfrac{mX_2}{(m-1)}+\dfrac{(m-1)}{m}X_3$

The sides b, c, and d are paralleled with the corresponding sides of the resonant delta GKL and a non-resonant delta with sides b_1, c_1, and d_1 is obtained. The total impedance is then

$$Z=a_1+\frac{b_1\,(c_1+d_1)}{b_1+c_1+d_1}$$

The currents in the network may now be found by applying Kirchoff's laws.

The writer wishes to take this opportunity to acknowledge the constructive criticisms of his work by many engineers and members of the Testing Department.

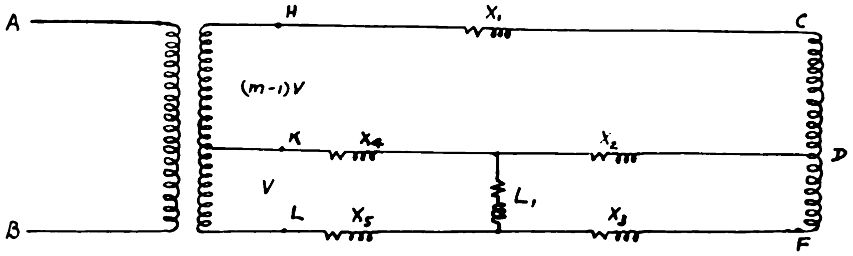

Fig. 9

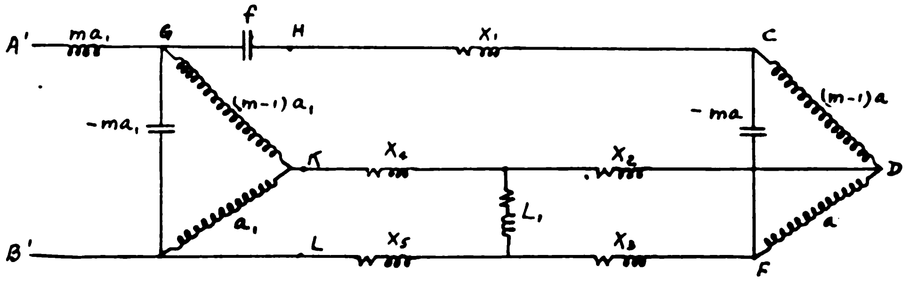

Fig. 9(a)

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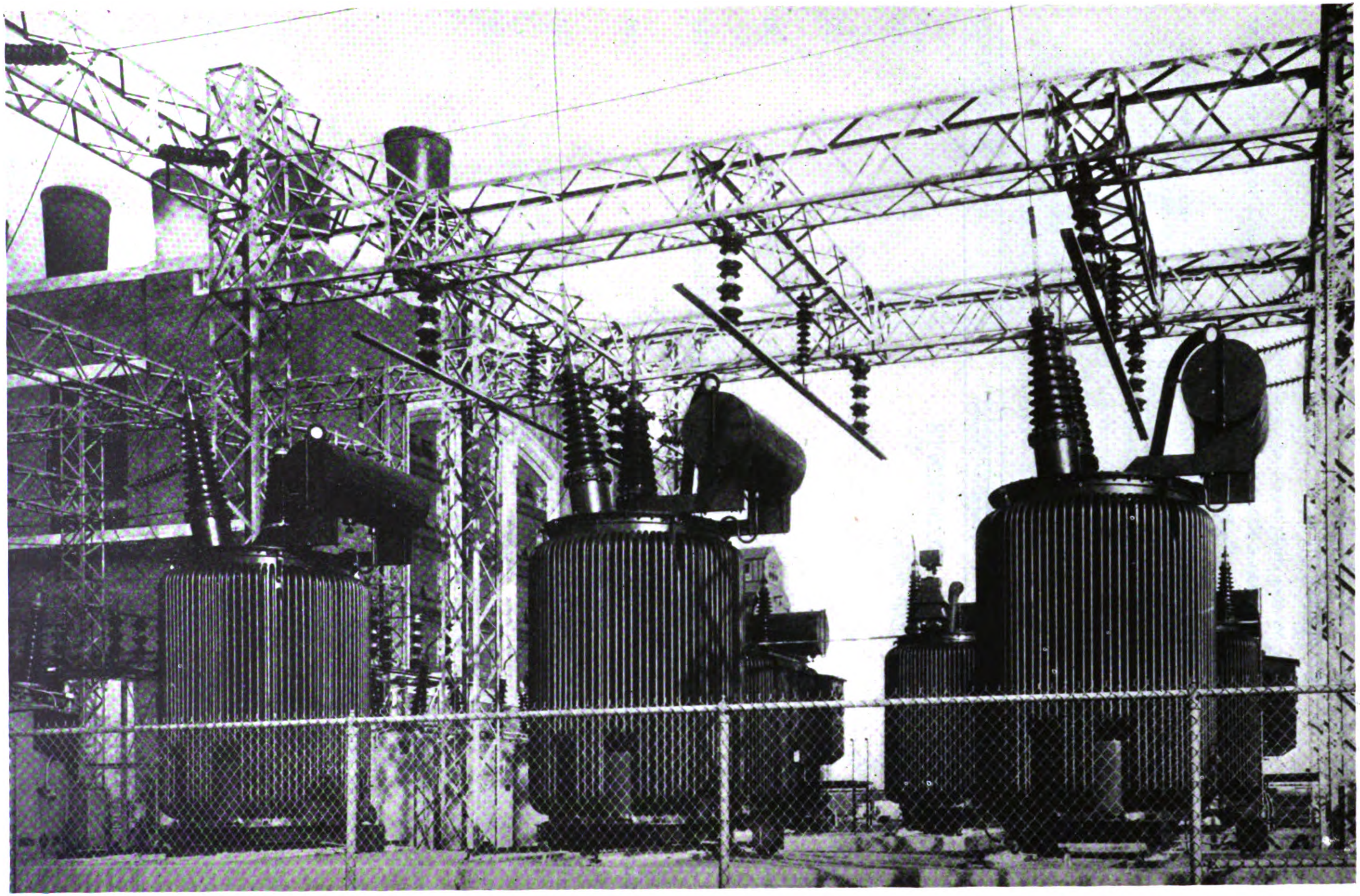


THE BODYGUARD OF A CENTRAL STATION

In modern generating practice more and more use is being made of reactors as protection against surges of current. In some installations the reactors are of a size comparable to that of large transformers. The above 2800-kv-a. oil-immersed reactors are installed in the 120-kv. bus of the 375,000-kv-a. Trenton Channel Station of the Detroit Edison Company. (*See p. 156*)

GENERAL ELECTRIC REVIEW

Vol. 32 **March, 1929** **No. 3**

CORPORATIONS

We were only in the schoolroom days of our civilization when we each depended upon our own individual efforts.

In our present state of civilization where, in some few countries, coöperation through corporate effort has proved the efficiency of corporations, we have reached our state of adolescence.

Man will attain his majority and reach the full flower of manhood only when all nations become organized as individuals and the world becomes an organic whole with each national organ playing its useful part in a world organization.

These conclusions were forced upon us as we read Dr. Whitney's article, "Coöperation and Corporations," published in this issue.

If we could review the history of the last half-, or even quarter-century, we should find that the great advances made in the world have come through corporate effort and the greatest failures when coöperation ceased to exist.

Just as Nature builds up her most complex, but highly efficient, bodies with individual organs which in turn are composed of single cells, so must Man, to reach his highest and most efficient state, build up his world body from national organs each of which will ultimately be composed of individual corporations working in harmony for both national and world-wide efficiency and good.

A quarter of a century ago, America was afraid of her large corporations; in fact, there were many who were afraid of anything big. Today, we are waking up to the fact that our prosperity and greatness are the direct products of coöperative effort.

> "Pray God our greatness may not fail
> Through craven fears of being great."

If some genius could and would write a true account of what American corporations have done for the advancement of America in particular and for the world as a whole, it would be a most conspicuous and valuable contribution to modern literature.

Such a book would reveal that it is the large corporations with their research; their physical, chemical, and engineering developments; discoveries and inventions; improved manufacturing processes; methods of distribution; up-to-date management; salesmanship and advertising ability, that have taken the burden from human shoulders and placed it on machines.

Only a few years ago the pessimists were wailing their song of how machines were making automatons and industrial slaves of our workmen. We are sick of both pessimists and pessimism. We would rather sing with Kipling in his "Secret of the Machine:"

> "We can pull and haul and push and lift and drive,
> We can print and plough and weave and heat and light,
> We can run and jump and swim and fly and dive,
> We can see and hear and count and read and write!"

It is just because the large corporations have developed machines with these and many other attributes that the old-time Socialistic Leader and Labor Demagogue have become back numbers.

The modern Industrial State outshines the wildest and brightest dreams of the socialists. It has given us the 100-horsepower workman—a man who controls machines instead of exerting himself. It has put into the discard forever the old State where freedom, leisure and luxury existed alone for the few and slavery for the many. It has turned our workmen into educated, self-respecting, householders, shareholders, and bondholders with a brighter and ever brighter future to look forward to as each year comes round.

In American corporations, the workman himself has made a vital contribution to the success of the whole scheme of things by abandoning old tactics of curtailing production and coming to a realization of the fact that his success can depend only upon increased production. The improved spirit of coöperation between the workman and the management is constantly leading to valuable suggestions for improvements in almost every phase of factory work and life, and such suggestions are being equitably rewarded. With our more modern spirit of coöperation the welfare and well-being of the workman receives as much consideration as those of the stockholders who desire increased dividends—in some cases, we believe, more. The modern workman is himself, or may be, a stockholder and can truly talk of *his* company. It is this spirit of mutual trust and coöperation that has metamorphosed the industrial world in the last few years and which is destined to lead to still happier results.

The world is full of paradoxes and not the least of them is that the large corporations in conjunction with the stock exchanges (both so much feared a few years ago as likely to lead to the accumulation of the national wealth by a few individuals or institutions) have turned out to be the most potent factors in leading to a more equitable distribution of wealth.

If the world at large will learn the lesson that "Coöperation and Corporations" is teaching us, the dream of some great and wise men may yet be consummated—

> "In the Parliament of man, the Federation of the world."

J. R. H.

Coöperation and Corporations

By **Dr. W. R. WHITNEY**

Director of Research Laboratory, General Electric Company

Dr. Whitney takes the building of a New York skyscraper as a symbol of our progress and proceeds to show how improvements have been achieved by the coöperation of corporations. This article was delivered as an address to students of Worcester Polytechnic Institute.—EDITOR

RECENTLY I stood on a balcony overlooking a street in New York. Directly opposite was an immense hole in the ground where a few days before had stood a very large building which with time had grown too small. It is to be replaced by a skyscraper. The hole was growing 60 feet into the solid rock. I was greatly impressed by the fact that practically no one seemed to be working about the place. Only about a dozen men were present, but there was a great noise and plenty of dust. The men who seemed to be leaning on the upper end of long pneumatic drills drew pay for working; but, I reflected, it is a long way from directing a pneumatic drill, which pounds away even if the operator rests, to cutting stone with a hand chisel. Perhaps the fellow seated at the levers of the shovel crane which so deftly lifted the enormous rocks displaced by the blasting, thought that he was working, as he skillfully lowered the rocks into huge auto trucks, but so also thought that idle fellow who whistled ever and anon to advise and direct the crane-operator who seemingly never even looked to see what he was doing. But I could not believe that those peacefully preoccupied men were really working as the 100,000 men worked who for 20 years cut the rock and built the ramps and pulled the stones into place on an Egyptian pyramid. Each one of these modern fellows knows that organization and mechanical power, steam, gas, and electric current, have given him over a hundred man-power per man, so each is now using his share. Looking for some sign of work or effort, I thought I saw two fellows who might ultimately get busy. Their job was to follow the heavily loaded trucks of rock up the steep incline leading to the street and to block the wheels in case the trucks stalled on the grade. I watched these two carefully, but they didn't work at all, for the trucks did not stop. Each of these, for fear he might have to work, had fastened a long handle to his block of wood so as to drag it up the ramp behind the trucks without lifting it. And yet I was told that a corporation was paying $80 a yard for the removal of that rock, and was glad to get it moved in this way.

Who moves it? Who works on this job? I maintain that intelligent organization and large corporations are doing it, and doing it so easily that probably the higher officers of each of the organizations are unaware of the particular work they do by this power-proxy system. So I went back over the job to see who was at work. I guessed Ingersoll-Rand was drilling the holes to take the dynamite which the du Ponts probably were making. I couldn't be sure that a General Electric shovel was lifting the rocks, but perhaps Bucyrus was, and I guessed that General Motors was carrying the rock away, with Standard Oil pushing the trucks on United States tires.

The men who a few centuries ago would have had to drive the slaves up that ramp with a whip had long ago thought out their part of the job and were probably now planning new undertakings.

After having dug this deep hole without much human energy, it is only fair to ask, "Of what use is my picture of it?" My answer is that if you now proceed to construct a skyscraper by following my general analytical method, you will get some idea of what organizations—corporations and their coöperation—are doing.

Notice how apparently easily the skeleton-like structure of corporation-made steel rises out of that hole. Except for the noise of riveters there is little doing until the floors are all in place. You wonder why someone does not put a gang of men at work in all that empty floor space. There ought to be a thousand bricklayers about, and the cry of "more mortar," "more brick" ought to be heard everywhere. But the Irish hodcarrier is now an alderman. Elevators and conveyors do his work. The enclosing walls of a building no longer start from the ground; they develop simultaneously at many floors. The steel outline soon fills in with stone blocks that were fitted for their place at some remote quarry. And at the quarry itself the man with the chisel whom one used to see is no longer part of the picture.

There is more to the building than steel and stone, and if you had to finish and furnish it you would again realize our changing economic conditions, the substitution of organization and organizations for individual labor. Is it to be a hotel? What artistic molder of porcelain is going to make those decorations, those tiled floors, that thousand bath tubs? They can only be made in some plant where human effort is an almost negligible part of the work. Is this progress? Is the public wrong in expecting a porcelain or enamelled bath tub in three-dollar rooms? It is useless to discuss the question. They must be made. No one is going back to tin tubs. Service is one thing and ceramic art another. We now express our appreciation of temperamental artistry in ceramics by having an artist decorate the office or foyer, so that everyone may enjoy his skill.

Are those miles of needed carpet to be hand woven in Axminister or Brussels? Impossible! A beautiful rug from Axminister or Brussels may well be here, because that art was admirable, but it is being wisely treated. It is hung on the wall where it may be appreciated, not depreciated by the hard wear of hurrying feet.

Think of trying to spin and weave the cotton sheeting, toweling, etc., which must go into such a building, by any process except the present one! In 1767, Hargraves made it possible to spin twenty or thirty cotton threads at the same time, with no more labor than had been used for spinning a single thread. Almost immediately Arkwright added the invention of the spinning frame which stretched, refined and twisted the threads to produce strong material. These devices were at first fought by the weavers of the time. The first Hargraves apparatus was twice destroyed by mobs. The patents of Arkwright were contested for many years by manufacturers of cotton goods, and the factories where his spinning frames were made were often attacked. There was little or no recognition at that time of the value of such labor-saving devices. Coöperation had first to develop and large organizations had to set up manufacturing plants. It is interesting to see that the rate of relief to labor on cotton fabrics has continued down to today. Due to continuous imrovements with the same old cotton, the rates of production of cotton sheeting reached 1 pound of cloth per man-hour in 1850. It was 2.28 in 1876, 3.20 in 1890, 3.84 in 1919, and 8.12 in 1925. There is no sign that the end has been reached.

In winter fruit from the south will arrive by aeroplane for this hotel. No slower transportation is satisfactory. Temporary preservation in refrigerators may be necessary, but the result is only continuing improvement. This is what man tries to do all his life. We imagine he does it better every succeeding day.

Whether it is better to have our breakfast brought to us daily from all points of the compass without our conscious exertion, or to kill a buffalo one year and keep jerked meat until we can kill another buffalo, may be a matter of opinion, but the general direction of mental effort is not so uncertain. From the very beginning man has always been changing his condition of labor in the one direction of less human horsepower per mental unit of satisfaction. In this process the complexity of coöperation has always played a growing part. The organizations which are almost unconsciously excavating the hole where the new building will be built are merely a large number of similar men. That is the ancient way of adding mechanical power. The new way calls for individuality, for differences in quality, for novelty in thought—for specialists. I often think of this difference as the difference between addition and multiplication. It is easy to appreciate the sum of a lot of numbers, for each individual retains his identity and no change seems introduced into the sum; but in multiplication, just as in coöperating or organizing with men of different instead of similar qualities, there is introduced, something new. This is the difference between a sum and a product. Here we see the peculiar paradox. By merging individuality within a group, products are produced which individual power could not produce. It is along this line of thought that we find complete justification both for the highest human specialization and the greatest coöperation. Engineering students are constantly aware of a choice between generalization and specialization. In the complexity of coöperating industry, the rate of progress depends on the degree of specialization and the number of coöperators. A general rule is that where many men are developing horsepower only, there application of mental medicine by specialists is indicated.

I have taken the building as my illustration because it has no end of reminders of our improving conditions. In all of them we see the same general plan. Apply less biceps but more cerebral cortex. There are plenty of good quips based on the question of what man will do with all the time he saves and the physical power which he reserves, but the physiologists show us that for the next few centuries at any rate, we can put them both into growing more interesting and into expanded brains.

Old Mr. Miller of Manhattan no longer delivers flour to Mrs. Waldorf-Astoria to be baked in the hotel oven. Windmills and gleaners and men with hoes are hanging on the hotel walls, and Fordson tractors, McCormick reapers, and International Harvesters are doing much of the farm work.

There are still some cities where hundreds of unhappy farmers drive milk wagons through mazes of streets. They cross and recross one another's routes and criminally multiply horse and human effort, but improvements are necessary to deliver milk to your new thousand-room hotel. Here the milk man and the iceman are out of place. Better organization; which means more mind and less horsepower, more cerebral cortex and less muscular tissue; is increasing. There are few fields in which it is not earning its way.

What we will do with what we save is always working itself out simultaneously with new efforts. Before the arrival of the mail, newspapers, telephone and radio, a hotel of a thousand rooms might have been an exaggerated Tower of London, but specialists in countless organizations now compete to serve and to entertain the occupants. Events of interest from everywhere pour into the room of the city prisoner.

Think of books and papers a moment. Publishers have so reduced the cost of printing that most of us have forgotten that books were originally written and hand-copied. The development of radio broadcasting is a new type of publication which is only possible through extensive coöperation or large corporations. The home movie, which is in its infancy, could never have been born but for the extensive work of large organizations who, seeing the promise of acceptable service, develop means for this kind of pleasure.

If you want another item of growing coöperation in civilization, contemplate a moment what is involved in the thousand or more telephones which must be put into that building. It is not a question of each individual making what he needs. He cannot make a telephone system nor even a single transmitter. It is not a question merely of finding a store from which the type of telephone instrument preferred by individuals may be purchased. Telephones must be more or less alike, and all suited for use with the feeble currents of the wiring system. But of how much service would the internal system be if one could communicate only within the building? No! The world is getting so small that it is exactly of that size where every room in every hotel everywhere must be interconnected. This calls for an organization not only national, but in some way international. It cannot be operated and controlled by any one individual except in conformity to the most civilized people in the most advanced countries.

Now consider for a minute who owns this building when it is completed? Naturally you say, the man who built it. But a man didn't build it. A lot of coöperating groups of men, working almost entirely by proxy and with impersonal power units, built it. Doubtless some one mind first pictured the new building, because that is the work which the individual mind has thus far always had to do. But a group of people planned the building, and before they could start, they got the interest—that is, the mental coöperation—of a group of bankers, who, in turn, interested a lot of capital, as they express it. This again may be mentality, but it is stored or accumulated mentality. So the groups of interested mentalities build the building for a lot of people whom they do not know, because, being stockholders, they change from time to time. Thus the building is built by a lot of mechanical energy, paid for out of the store of generally accumulated tokens of former mental efforts, and will be owned by people who made no individual exertions at the time. It is almost a publicly owned building. Anyone who wants to may own a part of it, if he will offer in exchange some of his stored results, or records of previous mental efforts. Pure physical effort alone could not have set aside such quantities of labor tokens for future use.

Nowadays (and that is fairly recently), the building and ownership of almost every large structure is becoming a more public matter than it was when individuals stood alone. A type of socialism is gaining solid ground with us, merely because as experiments are tried, those most satisfactory on the whole are being extended. I assume that if one plotted against time the growth of corporations, he would conclude that at no very distant date practically all of the large undertakings in construction and operation, in manufacture, transportation, supply, etc., will be owned by most of the people of the country. One might believe also that a large part of the ownership of the essential producing properties of the country would change hands almost daily. What I have in mind in this digression is that everything, including our most essential agencies for life, for comfort and happiness, is growing larger and larger and more and more the general property of the coöperating public, which in turn focuses a myriad of critical eyes upon the qualities and the promises of its possessions.

There is an additional type of coöperation in our new building. It is sometimes defined as the public's growing interest in stocks and bonds, or investment. By a self-fertilized growth it has become a natural process, not at all archaic, for the savings of labor to be put back as capital into corporations doing more or less public work. In fact, the more public the work (as in government undertakings) the surer the principle involved and the surer the interest evolved.

At the same historical period when we are using for the first time in human history a hundred mechanical man power per man, we are also using as capital or as a sort of storage capacity, an amount of wealth which may be expressed as the accumulation of countless billions of man-hours.

If our best young men do not take active, constructive interest in this going institution we call advancing civilization, make up your mind that others perhaps less intelligent will do so. This is more than an invitation, for it becomes a threat. The world has certainly always been committed to change, as a continued experiment. More novelties are being tried out now than ever before.

Bergson said, "Duration means the continued elevation of the absolutely new." So your preparation for life is not for merely living but for taking part in an ever-changing kind of living. If you cannot effect or affect a better change, you should still try to prevent harmful decrement by understanding the existing principles of construction.

When I was first tempted to leave a teaching position at Boston Tech. I thought I was deciding between working for myself and others by teaching and research or burying my possible individuality in a large soulless industry. The facts developed so strangely that they are perhaps worth giving you in some detail. I had been interested in colloidal chemistry and had reached the point where I wanted to see if all organic growth was not a case of electro-deposition of suspended colloidal matter by electric nerve currents. The idea has never left me. I even hoped that if I took the industrial job I might put a little time into further study of bio-chemistry. As a matter of fact, after overcoming my suspicions that industry involved submergence of individuality, I soon found that the limit of action was in my will, not in the industry. I could at any time make what studies I wanted. There is time for everything. And now after years of pleasant work I find my bio-chemistry more enjoyable than ever, and I am doing far more work by proxy in science than I could ever have done personally alone.

As evidence of my interest in encouraging others to take part in new coördinated activities, I may say enough to seem bold. I am convinced that most men will accomplish more in orderly team work than as individual race horses. I am willing to draw evidence from my own experience. This is special and personal, but you will appreciate that my aim in this talk is to help you. I am actually frightened at the extent of my opportunities to learn, because they must carry with them corresponding obligations. In the past week, for example, I have sat in a conference entirely devoted to the inauguration of a new and proper education of young college men, and on the same day listened a couple of hours to the remarkable novelties in aëronautics as presented by the Assistant Secretary of the Navy in charge of Aëronautics. As if to serve as counterirritant, I have sat with a committee on safety for submarines, and have read part of 4500 letters suggesting new submarine devices. In this same week I have listened to the report of experts who are experimenting on the effect of intense radio fields on dogs, where artificial fevers electrically produced may have biological significance. I have seen experiments on the destruction of insect pests on imported plants by a similar process and I have sat for an hour listening to radio-tube research men, who talked a language much too young for dictionaries. And this was not an unusual week! I wish more young men could realize that they may have opportunities similar to mine.

A corporation is just a condensate of coöperation. The corporations themselves are more nearly average than the specialized individuals who make them up. It is the hold-back effort or the conservatism of the many, which tempers, but does not destroy, the extreme will power or fervent activities of the individuals. This is coöperation. A man who is exceptionally inventive could seldom mature his inventions except for the non-inventive conservatism of others who have the means or capital for development because they are already specialized in conservatism.

I could not complete this picture of growing coöperation without a word about the growing system for carrying on. In our expanding stock markets, our Stock Exchange and the "Curb," we have a perfectly natural growth, because more and more people take stock in those things which they find by experiment to be helpful. Just as we have been increasing rapidly the use of previously unused power in place of the older human muscular energy, so we are also making general use of the stored or permanent tokens of usefully applied energy. That is what capital really is, and while this is admittedly not the place to discuss capital and wages, I have been dealing with the improved uses of labor and now I may close by referring to our increasing improvement in the use of capital. About a hundred years ago stock exchanges were being born. This means that the quotations which now fill whole pages of our daily journals are a novelty. Nowadays a five-million share day on the New York stock exchange is quite common, but everyone who takes interest in such things is aware of the rapid growth and extension of the principle. Everybody may take part nowadays in "big business," whether it be transportation or communication, or the manufacture of automobiles, of soap, chewing gum, or gunpowder. It would spoil the story if it were true that everyone owned some of the stocks and bonds of all the thousands of organizations whose shares are daily quoted. We are merely on the way. To have arrived is of questionable value, but to be changing and growing has always been a good sign. And so we can say that at least during the past century there has developed a generally serviceable combination by which mechanical labor has been shifted more and more from muscles to machines, and by which the efficiency and power of those machines have been continually augmented by what is really the mere loan of the tokens of previous efforts, this loan having been rapidly systematized by what we call our stock exchanges. In reality, then, the machinery which at first merely relieved man of the hardest kinds of mechanical work has now become complex enough to reward him liberally for the loan of the equivalent of that mechanical work.

Electrical Equipment in North Station, Boston; Novel Features of Flexibility and Economy

Old Wire Systems—New System—Economies

By J. C. RUNYON
Consulting Engineer, New York

THE new North Station at Boston, Mass., recently opened by the Boston and Maine Railroad furnishes many fine examples of modern engineering. A complete description of the electrical work alone would be too extensive, so this article is devoted principally to the new wiring developments.

The Station covers a plot more than 200 by 400 feet, with the Coliseum above. The transformer vaults for the Station and for the Coliseum were placed as near as possible to the load centers and are supplied from a 4000-volt switchboard. Each vault is provided with a remote control release switch, controlling the respective oil circuit breaker on the 4000-volt board, and pilot lights to indicate the "on" and "off" positions. The lighting transformers are connected delta-star with 115/200-volt secondaries, and the power transformers delta-delta 230-volt secondaries. Reserve transformers are provided for breakdown service.

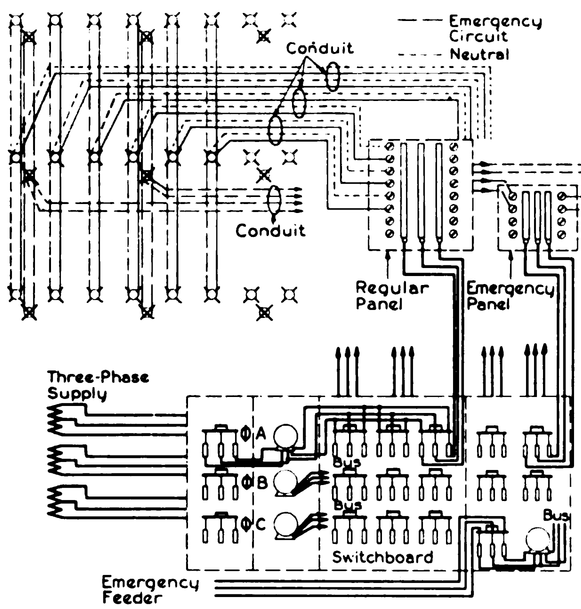

Emergency Circuit
Neutral
Conduit
Conduit
Regular Panel
Emergency Panel
Three-Phase Supply
ΦA
ΦB
ΦC
Bus
Bus
Bus
Switchboard
Emergency Feeder

Fig. 1. A Typical Layout Showing the Quantity of Wiring in the Conventional Three-phase Nine-wire System

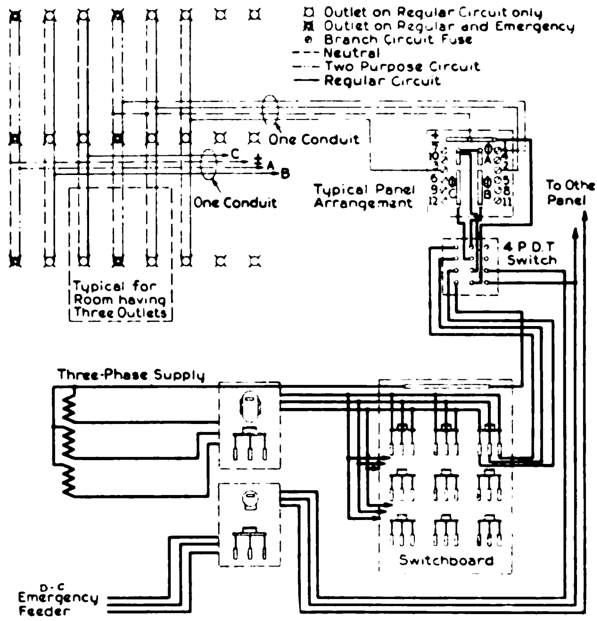

Outlet on Regular Circuit only
Outlet on Regular and Emergency
Branch Circuit Fuse
Neutral
Two Purpose Circuit
Regular Circuit
One Conduit
C
A
B
One Conduit
Typical Panel Arrangement
To Other Panel
4 P.D.T Switch
Typical for Room having Three Outlets
Three-Phase Supply
Switchboard
D-C Emergency Feeder

Fig. 2. Layout of the Runyon Wiring System, Showing Reduction in Quantity of Wiring and Provision for an Emergency System Without Extra Wiring

The newly devised system of wiring embodies features of economy and flexibility that give promise of revolutionizing future wiring plans. A brief review of wiring developments will assist in explaining the new features.

Originally, lighting systems developed the 110/220-volt Edison d-c. wiring. This proved so satisfactory that with the advent of a-c. it was still maintained in the single-phase systems. With the more general use of three phase during recent years this three-wire system has been adhered to by conservative engineers, to the extent of applying it to each phase individually, making a cumbersome 9-wire lighting system. This 9-wire system is shown in Fig. 1. Recently a few engineers adopted the star connection for secondary and ran four-wire mains, of 115-200 volts, to the distribution panels, but held to the two-wire branch circuit. This practice limited each branch circuit to its given area and did not permit economic emergency lighting, but required a separate system to be installed where emergency lighting was desired. This involved a duplication of panels, conduits, wiring and outlets, with consequent additional space.

In designing the electrical equipment for the North Station the writer was confronted with many limiting features. In the first place, the public nature of the building, and the great traffic through it, made it essential to provide every facility to assure lighting at all times. The building had no basement for equipment and the space not occupied for Station purposes is very valuable as rentable areas. Economy of cost is always a governing factor, but in this case space and safety were even more important. Even the size and quantity of conduits had to be considered; and extra long branch circuits were necessary.

The solution of these problems is shown by comparing Fig. 2 with Fig. 1. A simplified diagram of each of these systems is given in Fig. 3 for further comparison. In the first place the modern 4-wire 3-phase system of mains and panels was adopted. This reduced the size of the switchboard and the quantity of copper and conduits for the mains. Heretofore lighting circuits have been limited to a single phase, and the failure of any phase would result in no light for an entire section of the building. This deficiency was overcome, and light distribution assured, by carrying out the branch circuits on the 4-wire 3-phase system and using outlets distributed with relation to phase. More explicitly, the lights in any section were in rows having a sequence of phase A-B-C-A-B-C, etc. This accomplished four new features: (1) An equal light distribution in event of failure of one or two phases, (2) Absolute balance of phases, (3) Economy of wire and conduit, and (4) Provision for emergency lighting without additional wiring.

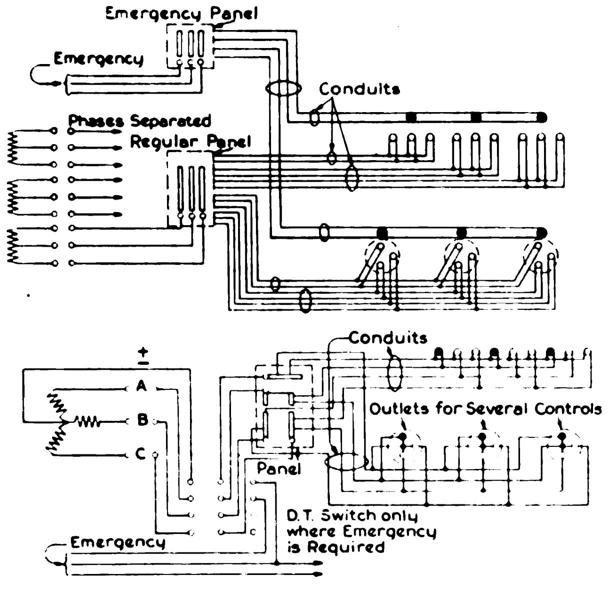


Fig. 3. A Comparison of the Conventional System (above) with the Runyon System (below), Wherein 18 Conductors and Six or Seven Conduits Are Supplanted by Eight Conductors and Two Conduits in Accomplishing the Same Results

So that this system could be readily carried out the panels were numbered on the branch circuits as to phase instead of the usual consecutive circuit numbers, *i.e.*, phase A No. 1-4-7-10, etc., phase B No. 2-5-8-11, etc., and phase C No. 3-6-9-12, etc. With this numbering any three consecutive numbers gave one of each phase, *e.g.*, 5-6-7 which are phases B-C-A. This avoided all confusion in phasing out circuits. Perhaps the greatest advantage of this system is its adaptability to emergency lighting. Boston has, in addition to its substantial a-c. plant, a good d-c. supply with storage battery reserve designed for almost any emergency. The d-c. supply was brought into the building and by simply adding a 4 P.D.T. switch on each Station panel the d-c. was made available to phase A, which on account of its even distribution through the Station performed the function of emergency lighting on d-c. without the addition of any panels, conduit wire, outlets or fixtures whatever. The Station has two panels containing over 200 branch circuits. It was felt that one phase or 1/3 of the total lighting would be adequate for emergency lighting. By supplying phase A on the first panel from one side of the d-c. and the second panel from the other side of the d-c. an economic feeder was obtained and a balance maintained. Consideration was given to making the throw over switch automatic, but it was felt that cases of this extra emergency would be so rare as to not assure positive action of the automatic switch and that manually-operated switches were preferable.

Being a new departure, before being adopted, these features were discussed with and approved by Mr. Walter J. Burke, Superintendent of Wires of the City of Boston, to whom the writer is indebted for valuable coöperation.

The accompanying diagrams show only a minimum number of circuits to illustrate the system. Some idea of the importance of this system may be had when it is considered that the estimated saving in the cost of the wiring on the North Station, due to this new arrangement, amounted to at least $40,000, and the reduced size of the switchboard released a rentable area probably worth $5000 per year.

Another interesting feature because of its simplicity, is the "Telechron" Clock installation. These clocks normally run on the a-c. of the building which is synchronized through the power station from Arlington. To assure continuity over even a slight failure of a-c. the system is equipped with an auxiliary motor-generator with relays for instantaneous transfer to the d-c. which maintains accurate time within a very few seconds.

The architects were Messrs. Funk and Wilcox, of Boston, with whom were associated Messrs. Fellheimer and Wagner, of New York. Builders were Dwight P. Robinson, Inc.; Electrical Contractors, Lord Electric Company. The major part of the electric equipment was furnished by General Electric Company.

The Influence of Glaze on Insulator Strength

Physical Characteristics—Mechanical Strength with and without Glaze—Effect of Glaze

By D. H. ROWLAND
Research Engineer, Locke Insulator Corporation

When the wet process porcelain insulator was originally developed it was only natural that its manufacture should follow the methods established by experienced potters. These workers skilled as they were in the creation of useful pottery were here faced, however, with entirely new problems. Nothing was known of the inherent characteristics of electrical porcelain and even when such problems were tackled by mechanical engineers difficulties of a far-reaching nature were encountered.

Some of the earlier work was very misleading in its character owing to unaccounted for variables. Ordinary physical characteristics of porcelain such as tensile strength, compressive strength, modulus of elasticity, and coefficient of expansion, seemed almost impossible to arrive at. For a long time the tensile strength of good porcelain was supposed to be as low as 1500 lb. per sq. in. This tensile strength has since been determined as between 5000 and 6000 lb. per sq. in. on a cross-sectional area of one sq. in. It is known now that this low figure was due to extreme brittleness of the material, which makes it almost impossible to deliver a test load to a sample, and to distribute this load in such a manner as to avoid a progressive failure. Such a tendency is well known in the case of cast iron. In porcelain it is much more severe. When pulling specimens as shaped in Fig. 1-A, pieces of non-ductile material, with sharp corners, will break along a line *cc* at lower values than will rods of the same cross section rounded off as in Fig. 1-B. From a realization of this characteristic it is only a step to a realization of the tremendous effect which surface conditions have upon the mechanical strength of porcelain.

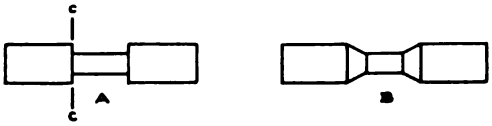


Fig. 1

It is the object of this article to present certain test data in this connection, and to point out certain features of the mechanical design of porcelain resulting from this work.

Hundreds of porcelain rods, $1\frac{1}{8}$ by 6 in., were made up and broken by transverse load application as in Fig. 2. These rods were made with the greatest care and fired in the same saggers, the different groups being intermingled so that all received identical treatment except in the case of one variable, *i.e.*, the surface condition. The rods were divided into 8 groups of approximately 25 to 30 rods, each group being dipped in a different type of glaze with the exception of Group 1, which was left unglazed. In all cases the glaze appeared to be normal with the exception of Group 8, which was purposely treated with a "bad-fitting" glaze. In this case crazing of the glaze after firing was apparent to the naked eye. The thickness of the glaze was in every case less than $\frac{1}{64}$ of an inch. Table I gives the average strengths of these various groups together with a mean variation.

Taking the unglazed rod as a base it will be seen that it is possible to increase, or decrease, the strength of the porcelain almost at will by glazing. Group 8 shows a reduction in strength of over 60 per cent, whereas Group 5 shows practically an identical increase in strength over the unglazed porcelain.

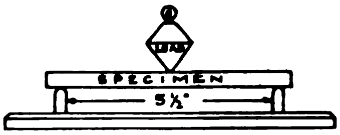


Fig. 2

The explanation of this phenomenon is quite simple. Fig. 3 shows a sketch of a magnified section taken across a hair crack in the glaze on a piece of porcelain. If the glaze were in tension due to some external load, and if the angle *A* were almost zero, it is evident that the stress at the point *A* would be practically infinite, and the crack would extend into the material. Further, it is obvious that the less ductile the material the greater this stress would be. If the specimen were of a soft material, instead of cracking the small defect shown in Fig. 3 would smooth out without causing a marked decrease in mechanical strength. Porcelain, however, is much on the order of glass and, as with glass, the first step if it is desired to break or cut it is to make a small surface scratch.

Moreover a piece of porcelain may appear to be perfect in all respects and yet the glaze may be under a condition of tensile stress such that in a few years' time crazing will take place. Even if this crazing does not occur, the tensile stress in the glaze will be added to that produced by some external load, or to the load caused by thermal changes, and thus the ultimate strength and lasting quality of the ware will be greatly decreased. The evidence of this is shown in Table I. Group 2 and Group 5 are the same except for a slight difference in the fit of the glaze. It is also reasonable to expect if this theory of the mechanics of failures is correct that the properly glazed specimens would be stronger than the unglazed specimens with their relatively rougher surfaces. This is also borne out by experiment as shown by Groups 1 and 5. Group 1 is unglazed.

A thorough understanding of the importance of the above principles has led to many interesting practical applications in porcelain insulator designs. Important increases in mechanical strength have resulted.

It is evident that the first problem is one of ceramics. The glaze and porcelain must be so balanced as to avoid tension in the surface. All glazes should be based on such molecular formulas that changes in colors will not affect the physical characteristics.

Sometimes this is very hard to accomplish, especially since in America electrical porcelain, unlike decorative pottery, goes through only one firing. A very small quantity of coloring oxide will often influence the strength of a glaze quite markedly. As a general rule, besides increasing the strength of porcelain, a good surface will bring the high and low values of the separate pieces much closer together. This, of course, is greatly to be desired.

It is impossible at present to make separate trials on a particular glaze and porcelain, and predict absolutely how these two materials will work together. They must be combined and tested for strength as has been described above. The preparation and firing of the samples must be done with extreme care in order to avoid the introduction of unaccounted for variables. In designs where sand fired in the glaze is used for cement grips, it is of extreme importance to get enough glaze between the sand particles otherwise the surface of the porcelain will be materially weakened. This point cannot be over-emphasized.

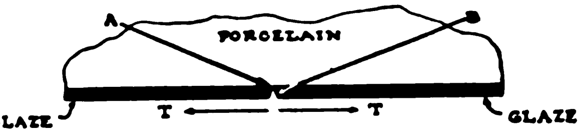


Fig. 3

It is beyond the scope of this article to go into the methods of plant control, inspection, and testing which are an essential part of good porcelain, but it can be said with certainty that the best engineering in the world will be of no avail in producing good insulators unless the ceramic work is complete to the last detail.

Let us now consider the mechanical design of a porcelain insulator. The point at which the mechanical design of an insulator diverges from everyday routine principles, and the point at which trouble has so often occurred in the past, is the joint between the metal hardware and ceramic material. Principles which apply to much assembly work with other materials must here be thrown aside, and instead of an absolutely inflexible joint these joints must be decidedly flexible in character. They must be capable of slipping an infinitesimal amount under stress, and thus distribute the load over the entire surface. If such movement is not provided for, concentrated point or line stresses cause progressive failure of the porcelain and the insulator will fail at a very low figure.

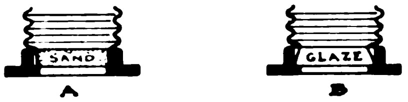


Fig. 4

This is nowhere better illustrated than in the design of bus bar supports. Where strength is not the main consideration the deciding factor in the design becomes leakage distance. Even so it has been found possible, without decreasing the leakage distance, to greatly increase the strength of such supports. The modification necessary to accomplish this, and correct glazing of the contact surfaces, allows the necessary amount of movement to distribute the load properly.

But where strength is a necessity, principles developed by the above cited tests come more fully into action. Supports of this type, from a mechanical standpoint, are designed on the basis of the side pull from the upper hardware which they will carry without breaking. Fig. 4-A shows the lower hardware of a typical bus bar support in section with the porcelain fitted into it. The bond between the metal and the porcelain is usually Portland cement.

In this design very little flexibility occurs in the joint between the porcelain and the hardware with the result that side pull places a definite concentrated line of stress on the porcelain at the joint. Unless the glaze is exact in every detail this means failure at a low figure. With a glaze such as that used on the rods

TABLE I

Group	1 Unglazed	2 Glazed	3 Glazed	4 Glazed	5 Glazed	6 Glazed	7 Glazed	8 Bad-fitting Glaze
Average strength in lb......	1061	1016	1299	1299	1716	989	957	384
Per cent mean variation....	4.6	3.6	9.35	8.9	3.8	6.25	4.36	5.5

shown in Table I; Group 5, this piece will develop its highest possible mechanical value. This value can be still further increased by so modifying the design as to allow an infinitesimal movement of the porcelain within the hardware which distributes the load when a pull is exerted. This type is shown in Fig. 4-B.

In the above discussion the very slight movement between the metal and porcelain, necessary from the mechanical standpoint, was between the cement and insulator. It is perfectly possible to design so that the movement is between the metal and cement. The disadvantages of this is that it is more difficult to obtain uniformity owing to the relative roughness of the metal surface. In all cases the amount of flexibility in the hardware is of great importance.

In the past there has been a great deal of discussion as to the possible aging of porcelain in service. It is only natural for those interested to wish to know what influence the surface condition of a piece of ware, which affects its strength so markedly, would have on its lasting ability in service. There is no definite answer to this question. We do know, however, that crazing of the glaze on insulators which are poorly made sometimes takes place after several years in service. There is no doubt that such a condition would go a long way towards producing an incipient failure due to a progressive crack gradually working through the porcelain. Undoubtedly, where the insulators are subject to much vibration or shock, the surface strength is of extreme importance.

From an electrical standpoint little difference has been observed between ceramic materials with a good glaze and those with a poor one. In this connection it must be remembered, however, that in nearly every case of failure of modern insulators that a mechanical crack is the initial cause of the electrical failure.

Summary

(1). It is only recently that electrical porcelain has reached a state very far removed from old-time pottery, from which it originated.

(2). Designers have been handicapped by not understanding the physical characteristics of porcelain.

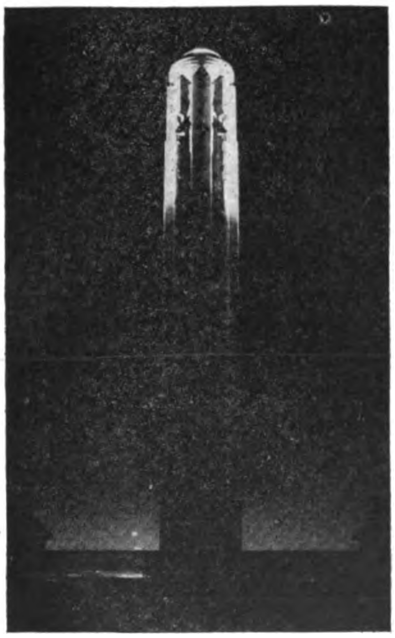
(3). It has been found that, other things being equal, the surface condition of porcelain has a tremendous influence on its strength, especially when the surface is subjected to a tensile stress. This point most certainly has been overlooked in the past.

(4). Ceramic materials have certain characteristics similar to cast iron but much more accentuated. In taking hold of porcelain with hardware, provision must be made for proper stress distribution.

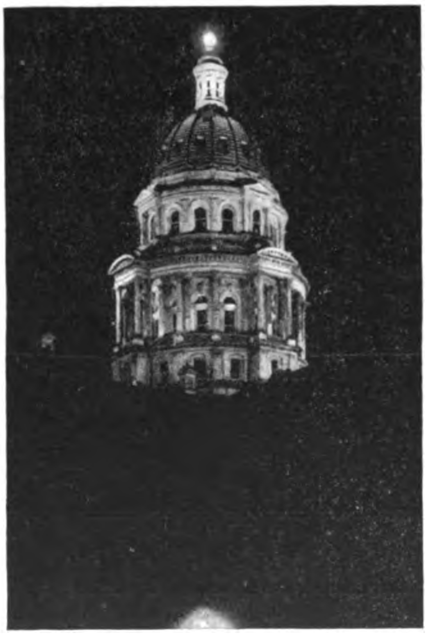
(5). There is not much doubt that the surface glaze has an effect on the so-called aging of porcelain, especially when subjected to vibration.

(6). Surface conditions do not influence the dielectric strength of ceramic material when no concurrent mechanical load is applied. Nearly all electrical failures of insulators are preceded by a mechanical fault.

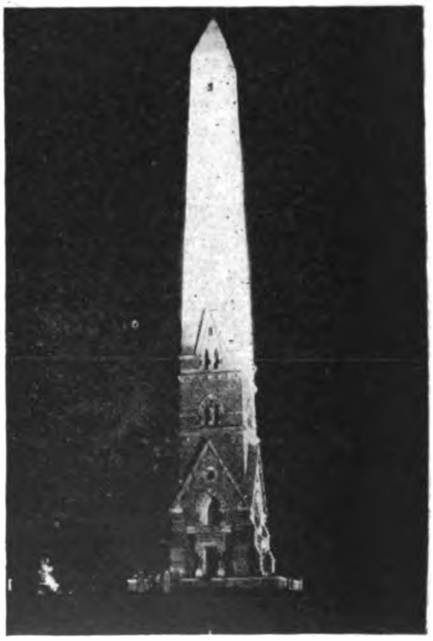
Floodlighting of Notable Shafts and Domes



Liberty Memorial
Kansas City (Mo.)



State Capitol
Denver (Colo.)



Saratoga Battlefield Monument
Schuylerville (N. Y.)

The Operation of Radio Receiving Tube Filaments on Alternating Current

PART I

By DR. K. H. KINGDON and H. M. MOTT-SMITH, JR.
Research Laboratory, General Electric Company

Recent radio developments permit the operation of tubes from a-c. lighting circuits, but when the filaments are heated by a.c. inherent disturbances are caused in the receiving circuit. The authors analyze these and show how to reduce them to a minimum. In Part I these problems are discussed for tubes used as amplifiers; in Part II tubes used as grid-leak detectors will be dealt with.—EDITOR

I. Introduction

WHEN alternating current is used to heat the filament of a triode vacuum tube, three important effects are produced: (1) a fluctuating potential drop along the filament, (2) a fluctuating magnetic field around the filament, and (3) fluctuations in filament temperature. These fluctuations directly cause three different kinds of disturbances in the plate current, which we shall call respectively: (1) the primary potential ripple, (2) the primary magnetic ripple, and (3) the primary temperature ripple. In addition, if the tube is being used as a detector with grid-leak, the alternating filament current produces disturbances in the grid current similar to those in the plate current. These grid current fluctuations passing through the grid-leak cause fluctuations in the grid potential, and therefore cause a ripple in the plate current. We shall refer to these plate current disturbances as secondary potential, magnetic, and temperature ripples respectively.

This analysis accounts for all the types of ripple observed. It may be mentioned in passing that disturbances produced by "grid action" of one part of the filament on another (as in the ordinary V filament) appear to be negligible in all the tubes which we have studied. We shall develop quantitative theories of the various types of ripple, and compare the results with experiments.

In calculating a ripple we shall find it convenient to replace a three-element tube (triode) by an equivalent two-element tube (diode) having cylindrical symmetry. It is possible to do this because of the fact that most of the space charge is concentrated in the region between the filament and the grid, and at the same time the magnetic field is a maximum at the surface of the filament. Thus we commit no great error in the calculations by neglecting the part of the electron path between the grid and the anode. This amounts to replacing the actual grid and anode by an equivalent anode surface nearly coinciding with the envelope of the grid, brought to a suitable potential. We can go even further and take this equivalent surface to be a cylinder concentric with the filament even for tubes of irregular shape, because the greater part of the effects producing the ripple take place in a region very near the filament where the lines of force are approximately radial. In such non-cylindrical structures we should expect to find that a fair approximation to the radius of the equivalent cylindrical anode is the shortest distance between the filament and grid, since the part of the grid nearest the filament has the greatest influence on the anode current. The experimental results show that this approximation actually is good even for tubes departing widely from the cylindrical shape. The potential of this equivalent anode is to be taken as

$$E_d = (E_p + \mu E_g) / (1+\mu) \qquad (1)$$

where E_p is the plate voltage of the triode, E_g the grid voltage and μ the amplification constant. This is in agreement with the rule followed in the derivation of the usual formulas for the impedance of a triode.

II. The Primary Potential Ripple—Elimination of the Component of Fundamental Frequency

Considering first the effect of the drop of potential along the filament on the anode current, and assuming for the present that the filament emits uniformly along its whole length, we have the well-known rule that the anode current is proportional to the difference between the five-halves powers of the potentials of the two ends of the filament with respect to the anode. (1) The basis of the calculation is indicated in Fig. 1, in which the oblique line AB represents the distribution of potential along the filament, e_f is the instantaneous voltage drop across the whole filament, E_d the voltage applied to the anode, and x the distance from the negative end of the filament to the point P at which the anode current is effectively returned, this distance being expressed as a fraction of the length of the filament. The return is made in the usual way, by means of a potentiometer shunted across the filament. If i is the instantaneous value of the total anode current and i_0 the value of this current when $e_f=0$, then if e_f is less than E_d the calculation shows that

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(1) Eccles, "Continuous Wave Wireless Telegraphy," Part I, p. 292.

$$\frac{i}{i_o}=\frac{2}{5}\frac{E_d}{e_f}\left\{\left[1+x\frac{e_f}{E_d}\right]^{5/2}-\left[1-(1-x)\frac{e_f}{E_d}\right]^{5/2}\right\} \qquad (2)$$

or expanding in powers of e_f/E_d which we assume to be small

$$\frac{i}{i_o}=1+\frac{3}{4}\frac{e_f}{E_d}\{2x-1\}+\frac{1}{8}\frac{e_f^2}{E_d^2}\{x^3+(1-x)^3\}$$
$$-\frac{1}{64}\frac{e_f^3}{E_d^3}\{x^4-(1-x)^4\}+\cdots\cdot \qquad (3)$$

Equation (2) is derived on the assumption that each element of the filament contributes independently a current proportional to the three-halves power of the voltage difference between the element and the anode. This neglects the effect of the emission velocities of the electrons, and other less important factors such as the effect of contiguous parts of the filament on the element considered. It is to be observed however that in any case the anode current can be represented by a series of the form of Equation (3), the only effect of a different law from that used above being to change somewhat the value of the numerical coefficients. Most of the conclusions following depend only on the form of the series, not on the values of the coefficients. The experiments show that actually Formula (2) is accurate enough to represent the results in the cases considered.

When the filament is heated with alternating current, e_f will vary periodically and the effect on the anode current can be pictured by imagining the line AB to perform oscillations about the point P. It is immediately evident that when P is not midway between A and B the anode current will contain a periodic component of the same frequency and phase as the filament current. The amplitude of this component is given approximately by the second term of series in Equation (3), taking e_f to be the amplitude of the filament voltage, supposed to be sinusoidal.

If however P is the midpoint of the filament, the fundamental frequency component in i disappears, because i is evidently independent of the direction of the filament voltage. At any instant the current from the positive half of the filament is less than when $e_f=0$ and that from the negative half of the filament is greater than when $e_f=0$. But as a result of the three-halves power law the increase in current from the negative end is greater than the decrease in current from the positive end, and therefore the anode current is greatest when e_f is a maximum (in either direction) and least when e_f is zero. There will thus still be a ripple in the anode current, but the main component of this ripple will have a frequency twice that of the filament voltage, and its maxima are in phase with the maxima of e_f^2.

In fact, on placing $x=\frac{1}{2}$ in the right-hand side of Equation (2) it does not vanish, but in the expansion given by (3) only even powers of e_f remain. If e_m is the maximum value of the filament voltage and i_m the maximum value of the anode current, then we find from Equation (2) for $x=\frac{1}{2}$

$$\frac{i_m-i_o}{i_o}=\frac{2}{5}\frac{E_d}{e_m}\left\{\left[1+\frac{1}{2}\frac{e_m}{E_d}\right]^{5/2}-\left[1-\frac{1}{2}\frac{e_m}{E_d}\right]^{5/2}\right\} \qquad (4)$$

which according to Equation (3) becomes for small values of e_m/E_d

$$\frac{i_m-i_o}{i_o}=\frac{1}{32}\frac{e_m^2}{E_d^2} \qquad (5)$$

It is to be noted that in this case i_o is the minimum value of the anode current, so that i_m-i_o is twice the amplitude of the second harmonic in the anode current (neglecting the amplitude of higher harmonics, which are small). Fig. 2 shows a logarithmic plot of Equation (4). It will be seen that the slope of the graph for small values of e_m/E_d is 2: this is the region where Equation (5) holds.

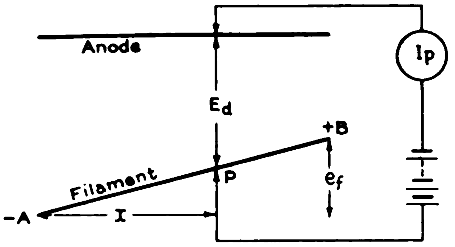

Fig. 1. Effective Anode Voltage at Various Points Along a Filament

According to Equation (5) the amplitude of the residual ripple left when the fundamental component is eliminated is proportional to the square of the small ratio e_m/E_d. On the other hand the amplitude of the fundamental itself is proportional to the first power of this ratio. This shows the importance of eliminating the fundamental by suitably adjusting the position of the point P. The question remains whether this is always possible.

We have to consider that in the general case even with no filament voltage drop the current to the anode may not be uniformly distributed along the filament, because of variations in emission, contact potential, grid spacing, or other irregularities. In addition, the filament heating current may contain harmonics. It is however sufficiently plain from Fig. 1 that in spite of such factors the component of fundamental frequency in the anode ripple can always be balanced out. For we can look upon the amplitude of this component as the sum of contributions from each element of the filament, the contributions being all of same phase, but positive for elements on one side of P and negative for elements on the other side. As P moves from one end of the filament to the other, the total amplitude therefore varies continuously from a positive to a negative value and so must pass through zero as P takes some intermediate position which we shall call the balance point.

But it is important to observe that if the filament heating current contains *even* harmonics the point of balance will not be the geometrical center of the filament even if the conditions along the filament are uniform. On the other hand if only odd harmonics are present the balance point is the geometrical center. Consequently a tube adjusted to balance when the filament heating current is sinusoidal will remain in balance if the filament supply contains odd harmonics, but it will no longer be in balance if even harmonics are present.

Finally, if there are irregularities in the distribution of the anode current, the balance point is not the geometrical center, nor is it the "current center" of the filament, the current center being defined as the point which divides the filament so that the anode currents from the two parts are equal when there is no voltage drop along the filament. As a matter of fact, the position of the balance point depends upon the wave-shape of the filament supply, so that a tube adjusted for one wave-shape will be out of balance when the wave-shape changes.

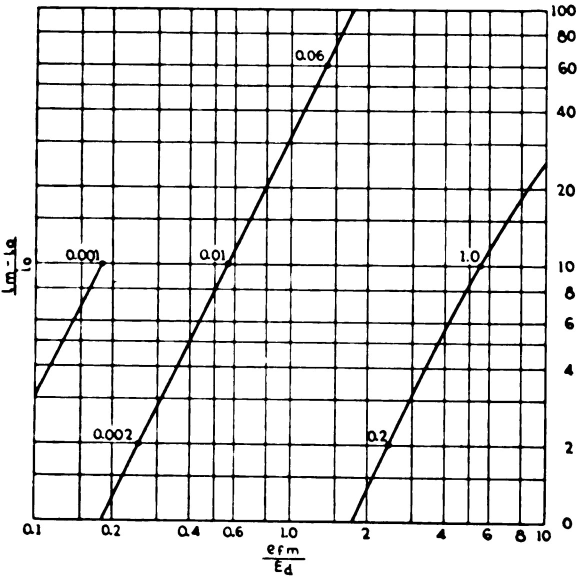

Fig. 2. Primary Potential Ripple in an Amplifier as a Function of Tube Constants

To illustrate these facts, let us suppose that at a fractional distance s from the geometrical center of the filament there is a spot which contributes a fraction a to the total anode current when $e_f = 0$. The effect of this will be equivalent to adding the quantity

$$a\left(1 + s\frac{e_f}{E_d}\right)^{3/2}$$

to the right-hand side of Equation (2) so that on expanding in powers of e_f/E_d the current is found to be proportional to

$$[1+a] + \frac{3}{4}\frac{e_f}{E_d}[(2x-1)+2as] + \frac{1}{8}\frac{e_f^2}{E_d^2}[x^3+(1-x)^3+3as^2]$$
$$-\frac{1}{64}\frac{e_f^3}{E_d^3}[x^4-(1-x)^4+4as^3] + \cdots \qquad (6)$$

For our purpose it will be sufficient to consider a filament current containing only the first three harmonics and so we will put e_f equal to

$$A\cos t + B\cos 2t + C\cos 3t \qquad (7)$$

and also put

$$x - \tfrac{1}{2} = x' \qquad (8)$$

so that x' denotes the fractional distance of the point P from the center of the filament. We assume that a is small. Then x' will also be small. Substituting from Equations (7) and (8) in (6) we find for the coefficient of $\cos t$ to the first order in x' and a the expression

$$\frac{3}{2}(x'+as)\frac{A}{E_d} + \frac{1}{32}\frac{B(A+C)}{E_d^2}$$
$$-\frac{3}{256}x'\frac{A^3+2AC^2+A^2C+B^2(2A+C)}{E_d^3} + \because\because \qquad (9)$$

Let us first assume that the tube is to be balanced for a filament supply free from harmonics. Putting $B=C=0$ in (9) we find that to reduce the resulting expression to zero we must have

$$x' = -as\Big/\left(1 - \frac{1}{64}\frac{A^2}{E_d^2}\right) \qquad (10)$$

very nearly, or practically $x' = -as$. The negative sign shows that the balance point is shifted from the center toward the high current spot on the filament. On the other hand it appears from Equation (6) that the "current center" of the filament is at $x' = -\tfrac{1}{2}a$. If now the filament thus adjusted is put on a supply containing harmonics, a fundamental component is introduced whose amplitude is found by substituting from (10) into (9) to be approximately

$$\frac{1}{32}\frac{AB}{E_d^2} + \frac{3}{256}as\frac{2AB^2+A^2C}{E_d^3} \qquad (11)$$

referred to the direct-current component as unity. Comparing this with the amplitude of the second harmonic ripple which is found from (6) or (5) to be nearly $\frac{1}{64}\frac{A^2}{E_d^2}$ we find the *ratio of the amplitudes of the first and second harmonics* to be

$$2\frac{B}{A} + \frac{3}{4}as\frac{A}{E_d}\left(\frac{C}{A} + 2\frac{B^2}{A^2}\right) \qquad (12)$$

From this expression we see that

(1). If a tube with a uniform filament ($a=0$) is balanced for a sinusoidal supply of filament current, the introduction of a second harmonic in the filament current causes the appearance of a fundamental frequency component in the anode ripple whose amplitude is 2 B/A times the amplitude of the double-frequency component.

(2). If a tube having irregularities in the distribution of anode current is balanced for sinusoidal filament supply, the introduction of a third harmonic in the filament current causes.

the appearance of a fundamental-frequency component in the anode ripple whose amplitude is

$$\frac{3}{4}\,as\,\frac{C}{E_d}$$

times the amplitude of the double-frequency component.

These results demonstrate the particularly bad effect due to the presence of a second harmonic in the filament current, especially when a tube is being operated under conditions such that the double-frequency component of the ripple is itself nearly eliminated by balancing the potential ripple against the magnetic ripple in the way we shall shortly describe. For instance, let us suppose that the double-frequency component has been reduced to one-tenth the value given above; then the introduction of a second harmonic having an amplitude five per cent of the fundamental in the filament supply will cause a 100 per cent increase in the amplitude of the anode ripple. The result will be the same if the tube has been balanced for any particular value of the second harmonic amplitude and this amplitude is then changed by five per cent of the fundamental amplitude. If the tube filament is being lighted from a transformer which also supplies power to a rectifying device (for instance, a B-battery eliminator) it may happen that variations in the load on the rectifier may cause considerable corresponding variations in the amplitude of the anode ripple.

III. Primary Magnetic Ripple

Let us now consider the effect of the magnetic field of the filament on the plate current of a diode. This field gives to the electrons going toward the plate a component of motion parallel to the filament, and this affects the anode current in two ways. In the first place, electrons starting from the ends of the filament may be caused to miss the anode, or to reach it when in the absence of the field they would not. If the tube is unsymmetrical this introduces a component of fundamental frequency in the anode ripple. In the second place, the total space charge due to each electron will be greater when the magnetic field is present than when it is absent, because the additional curvature introduced in the electron's path makes the time of transit longer.

The first effect will not occur when the anode is longer than the filament; and in actual tubes it can be neglected. All the fluctuations due to the magnetic field will be due to the second effect, which causes the anode current to decrease when the filament current increases (regardless of direction). Thus the magnetic field produces in the anode current a double-frequency ripple whose phase is *exactly opposite* to that of the potential ripple, since the maxima of the magnetic ripple occur when the filament current is zero.

The fractional change $\Delta i/i$ in the anode current produced by increasing the filament current from *zero* to the value I is a function of I, of the anode voltage E_d, the charge (e) and mass (m) of the electron, and of structural parameters. From dimensional considerations it follows that this function must be of the form

$$\frac{\Delta i}{i} = f\left(\frac{\frac{e}{m}I^2}{E_d},\ g\right)$$

where g is a homogeneous function of order zero in the dimensions of the tube; and f must be an even function of I since the two directions of the magnetic field clearly are equivalent. Also f must vanish when I does. Expanding f in a Taylor's series we therefore should expect that for small values of $\Delta i/i$ we could write

$$\frac{\Delta i}{i} = A\,\frac{\frac{e}{m}I^2}{E_d} \qquad (13)$$

where A is a constant depending on the tube dimensions.

The value of A can be found only in cases of simple geometry. We will carry out the calculation for the case of cylindrical symmetry. Let a long straight filament of radius r_o carrying the heating current I be surrounded by a coaxial cylindrical anode which collects an emission current i per unit length. To simplify the problem we neglect the initial velocities of the electrons and consider the filament surface to be an equipotential. If v_r is the radial velocity component of an electron at a distance r from the axis where the potential is V then(2)

$$v_r^2 = 2\,\frac{e}{m}\,V - \left(2\,I\,\frac{e}{m}\right)^2\left(\ln\frac{r}{r_o}\right)^2 \qquad (14)$$

Letting ρ stand for the space charge per unit volume at the distance r, we have the further equations

$$2\,\pi\,r\,\rho\,v_r = i$$

$$\frac{1}{r}\,\frac{d}{dr}\left(r\,\frac{dV}{dr}\right) = 4\,\pi\,\rho$$

On eliminating ρ and v_r between these three, we obtain the following equation governing the distribution of potential between the electrodes.

$$\frac{1}{r}\,\frac{d}{dr}\left(r\,\frac{dV}{dr}\right) = i\sqrt{\frac{2m}{e}}\;\frac{1}{\sqrt{V-\sigma\left(\ln\frac{r}{r_o}\right)^2}} \qquad (15)$$

in which we have put

$$\frac{2e}{m}\,I^2 = \sigma \qquad (16)$$

This equation is to be solved with the boundary conditions

$$V=0,\ \frac{\partial V}{\partial r}=0,\ \text{for } r=r_o \qquad (17)$$

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(2) Hull: *Phys. Rev.*, *25*, 647 (1925).

To solve the equation, we consider V to be a funtion of σ as well as of r, the current i remaining fixed. Then V can be expressed as a power series in σ, the coefficients being functions of r and the other parameters. The first term of the series is the value of V for $\sigma=0$ while the other coefficients are the successive partial derivatives of V with respect to σ evaluated at $\sigma=0$.

The solution of the equation for $\sigma=0$ is given by the ordinary space-charge equation for cylindrical electrodes ⁽³⁾

$$i=\frac{2\sqrt{2}}{9}\sqrt{\frac{e}{m}}\,(1/r\,\beta^2)\,(V_{\sigma=0})^{3/2} \tag{18}$$

In this equation β is a function of the ratio r/r_o. For large values of the ratio β approaches unity, while for small values β is proportional to ln r/r_o (*loc. cit.*).

We now proceed to differentiate (15) with respect to σ, then place $\sigma=0$ in the resulting equation. In this way we obtain a differential equation for the quantity

$$\left.\frac{dV}{d\sigma}\right|_{\sigma=0}=P \tag{19}$$

After substituting from (18) this equation is found to be

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dP}{dr}\right)=-\frac{2}{9}\,\frac{P-(\ln r/r_o)^2}{r\,\beta^2} \tag{20}$$

which by the substitution

$$\gamma=\ln\,(r/r_o) \tag{21}$$

reduces to the simpler form

$$\frac{d^2P}{d\gamma^2}+\frac{2}{9}\,\frac{P}{\beta^2}=\frac{2}{9}\,\frac{\gamma^2}{\beta^2} \tag{22}$$

This equation is to be solved with the same boundary conditions as before, *i.e.*

$$P=0,\ \frac{dP}{d\gamma}=0\ \text{for}\ \gamma=0 \tag{23}$$

An approximate solution $P_o(\gamma)$ of Equation (22) is readily obtained by assuming β^2 constant and equal to unity. This gives

$$P_o(\gamma)=\gamma^2-9\left(1-\cos\frac{\sqrt{2}}{3}\,\gamma\right) \tag{24}$$

The approximation is however not very good because the largest error in β is made in the region where the magnetic field is strongest, namely, the region near the filament. A convenient way ⁽⁴⁾ of correcting the above expression is to consider the variation $\delta P(\gamma)$ produced in the solution of (22) when the coefficient $1/\beta^2$, regarded as arbitrary, is subjected to a variation $\delta(1/\beta^2)$. By "varying" Equation (22) we obtain

$$\frac{d}{d\gamma^2}\delta P+\frac{2}{9}\,\delta P=-\frac{2}{9}\,[P_o(\gamma)-\gamma^2]\,\delta(1/\beta^2) \tag{25}$$

which is a linear differential equation for δP. We put $\delta(1/\beta^2)=1/\beta^2-1$, substitute for $P_o(\gamma)$ from (24) and solve the equation with the initial conditions (23) obtaining

$$\delta P=3\sqrt{2}\int_o^\gamma \sin\left\{\frac{\sqrt{2}}{3}\,(\gamma-s)\right\}\left(1-\cos\frac{\sqrt{2}}{3}\,s\right)(1/\beta^2-1)\,ds \tag{26}$$

The integral is most conveniently evaluated by numerical integration. The second variation δ^2P can be obtained by varying Equation (25) and going through a similar process. $P(\gamma)$ is then obtained from the series

$$P(\gamma)=P_o(\gamma)+\delta P(\gamma)+\tfrac{1}{2}\,\delta^2P(\gamma)+\,:\,:\,:$$

The successive terms diminish rapidly, especially for large values of γ. In this way the asympototic expression approached by P for large values of γ was found to be

$$P(\gamma)\cong\gamma^2-9+9.750\,\cos\left(\frac{\sqrt{2}}{3}\,\gamma-0.1665\right) \tag{27}$$

This gives $P(\gamma)$ with an error of one part in a hundred thousand at $\gamma=8$, ½ per cent at $\gamma=6$, 12.5 per cent at $\gamma=4$. The following table gives the true values for $P(\gamma)$ and for

$$Q(\gamma)=P(\gamma)/\gamma^2 \tag{28}$$

γ	$P(\gamma)$	$Q(\gamma)$	γ	$P(\gamma)$	$Q(\gamma)$
0.0	0.0	0.1000	4.5	7.152	0.3532
0.5	0.02851	0.1140	5.0	10.039	0.4016
1.0	0.1308	0.1308	6	18.24	0.5077
1.5	0.3387	0.1505	7	30.22	0.6168
2.0	0.6952	0.1738	8	46.27	0.7230
2.5	1.256	0.2010	9	66.21	0.8173
3.0	2.092	0.2324	10		0.8940
3.5	3.287	0.2683	13.5		1.00039
4.0	4.938	0.3086	15		0.99523

As γ increases from 0 to ∞, $Q(\gamma)$ begins with an initial value of one-tenth and approaches unity through a series of fluctuations of extremely small amplitude. The first maximum is at about $\gamma=13.5$.

Having now found the value of the quantity defined by Equation (19), we could in a similar manner differentiate Equation (15) twice with respect to σ and obtain a linear differential equation for the second partial derivative of V with respect to σ, evaluated at $\sigma=0$. This differential equation could be solved by using Equation (13) and the values just obtained for $P(\gamma)$. Proceeding in this way the coefficients of the power series for V could be found in succession. For our purposes the first two terms will suffice. The change in potential ΔV at any point brought about by the presence of the magnetic field is thus to the first order

$$\Delta V=\sigma\,P(\gamma) \tag{29}$$

By letting γ correspond to the coördinate of the anode, Equation (29) gives the increase in anode

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(3) Langmuir and Blodgett: *Phys. Rev.*, 24, 347 (1923).

(4) Volterra: *Lecons sur les fonctions de lignes*, p. 31.

potential required to keep the current unchanged when the magnetic field is changed from zero to its final value. If now the anode is brought back to its original potential, the anode current i will be decreased by an amount Δi which can be calculated by using Equation (18), since we are concerned only with values of σ near zero. Differentiating (18) logarithmically we find

$$\frac{\Delta i}{i}=\frac{3}{2}\frac{\Delta V}{V}$$

Equation (32) which is of the form of (13) enables one calculate directly the primary magnetic ripple for tubes of cylindrical structure. For tubes of other shapes, the more general formula, Equation (13), is found to hold; but the shape factor A can only be determined empirically from the data. The value thus found for A shows that, for reasons explained in Section I, Equation (32) can be used even for non-cylindrical tubes if we take for r the shortest distance between filament and grid.

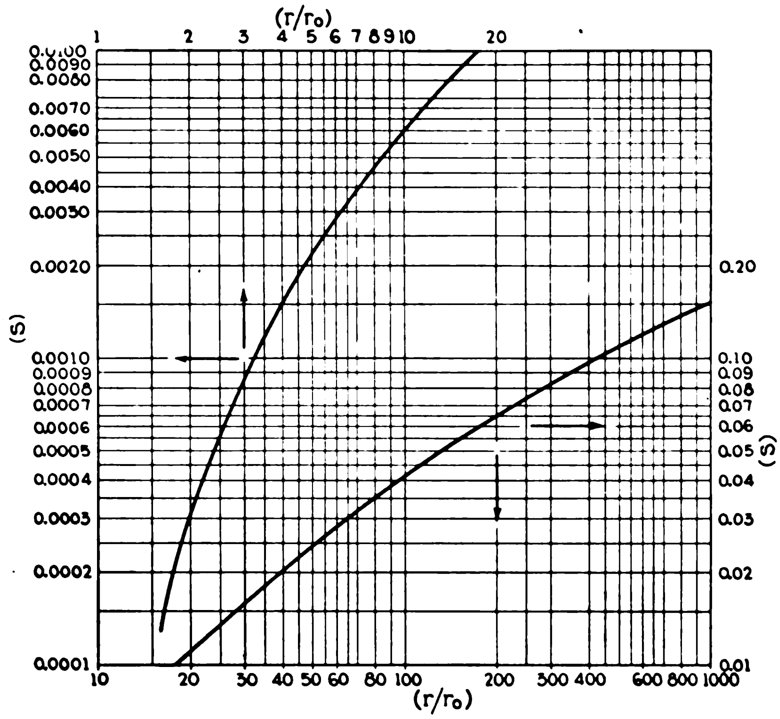

Fig. 3. Primary Magnetic Ripple in an Amplifier as a Function of Tube Constants

Placing $V=E_d$ and $\Delta i=i_m-i_o$ where i_m is the maximum and i_o the minimum value of the anode current, and substituting from (29) and (16) this becomes

$$\frac{i_m-i_o}{i_m}=3\frac{e}{m}I^2\,P(\gamma)=\frac{3}{2}\frac{V_c}{E_d}\,Q(\gamma) \qquad (30)$$

In the last equation V_c stands for the axiatron "cut-off" voltage, or the minimum anode potential for which the emitted electrons can reach the anode in the presence of the magnetic field of the filament. It is given by Hull's equation(5)

$$V_c=2\frac{e}{m}I^2\,(ln\ r/r_o)^2 \qquad (31)$$

In practical units Equation (30) can be written

$$\frac{i_m-i_o}{i_m}=0.00532\,\frac{I^2}{E_d}\,P(\gamma) \qquad (32)$$

Fig. 3 shows a plot of the quantity $(E_d/I^2)\ (i_m-i_o)/i_m$ as a function of r/r_o.

IV. Combination of Primary Potential and Magnetic Ripples

We have seen that the potential and magnetic ripples are of opposite phase. Further, Equations (5) and (32) show that the potential ripple changes faster with the diode voltage than does the magnetic. It is therefore possible, by a suitable choice of filament voltage and current, and plate and grid voltages, to balance the two ripples against one another. When the best balance has been secured there is usually a small residual disturbance due to end effects, so it is desirable to make both ripples small instead of endeavoring to obtain a perfect balance between two large ripples.

In the following we shall use i_{fm} (instead of I) for the maximum value of filament current; e_{fm} for the maximum filament voltage; and R_f for the filament resistance.

From Equations (5) and (32) we see that the condition for balance of small ripples is

$$\frac{1}{32}\left(\frac{e_{fm}}{E_d}\right)^2=\frac{0.00532\ i^2_{fm}}{E_d}\,P(\gamma)$$

or

$$R_f=\left(\frac{e_{fm}}{i_{fm}}\right)=\sqrt{0.170\,P(\gamma)}\,\sqrt{E_d} \qquad (33)$$

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(5) *loc. cit.*

Fig. 4 shows plots of R_f against $\sqrt{E_d}$ for various values of r/r_o. From this figure, then, one may select the tube constants which will give minimum combined ripple for any chosen grid and plate voltage.

V. Primary Temperature Ripple

This kind of ripple is of importance in tubes where the plate current is a considerable fraction of the total available emission. The filament temperature fluctuates with a frequency double that of the heating current, and the consequent fluctuations of emission may cause appreciable ripple in the plate current. The theory necessary for calculating the fluctuations of temperature has been given by Corbino,(6) and we shall merely quote his result.

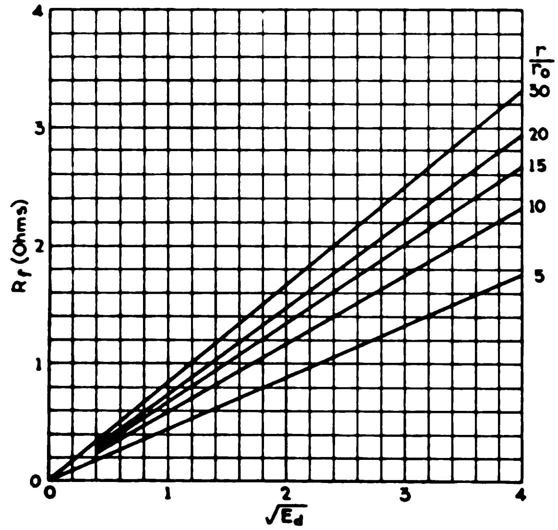

Fig. 4. Conditions for Balance of Primary Magnetic and Potential Ripples in an Amplifier Tube

Let $f(T)$ be the energy radiated from the filament at temperature T, R_m the mean resistance, c the heat capacity, a the temperature coefficient of resistance, and $e_o \sin \omega t$ the impressed e.m.f. The instantaneous temperature T differs from the mean temperature T_m by θ degrees, so that $T = T_m + \theta$. We have at once from the energy balance

$$c\,\frac{dT}{dt} + f(T) = \frac{e_o^2 \sin^2 \omega t}{R_m (1 + a\,\theta)}$$

Whence $\theta = \theta_o \cos (2\,\omega t - \phi)$

where $\theta_o = -\frac{e_o^2}{2\,R_m}\,\frac{\cos \phi}{Q}$

$$\tan \phi = \frac{2\,\omega\,c}{Q}$$

And $Q = a\,f(T_m) + f'(T_m)$

Put $f(T) = sT^{\beta}$, where β has the values(7) 5.65, 4.99, and 4.66 at 1000, 1900, and 2500 deg. K. respectively.

Hence we have finally for the approximate values

$$\theta_o = \frac{\cos \phi}{a + \beta / T_m} \tag{34}$$

$$\tan \phi = \frac{2\,c\,\omega}{f(T_m)\,(a + \beta / T_m)} \tag{35}$$

These expressions enable us to calculate the maximum amplitude and the phase of the temperature variations. Their application to the determination of the primary temperature ripple will be illustrated in the experimental section.

Before entering on the theory of the secondary ripples, we shall describe the experiments made to test the theory of the primary ripples.

VI. Experiments

The tubes studied were either of standard design, or else of similar types being developed in the laboratory. There was no provision for the elimination of end effects so that a high degree of accuracy cannot be expected in the measurements. Our aim was only to carry the measurements far enough to see that no important cause of ripple remained obscure, or was overlooked.

The filament of the tube under study was heated by 60 cycle a.c. The plate battery was connected to the anode through a protective lamp and the measuring instruments; there was no inductance in the plate circuit comparable with the impedance of the tube, so that there was no phase-shift from this cause. The grid voltage was kept fixed by means of a small potentiometer, no grid resistance being used. Both grid and plate returns were made to the tap of a low-impedance slide-wire potentiometer whose ends were connected directly across the filament. Throughout the experiments the position of this tap was kept adjusted so that the component of fundamental frequency in the ripple was balanced out. The balance position of the tap is usually near the center of the potentiometer, but in some tubes non-uniformity of electron emission over the filament surface, or variation of grid spacing, brings the best balance position of the tap rather off center.

The plate circuit included a milliameter and an Einthoven galvanometer, the latter having an auxiliary battery and resistance connected across it to balance out the d-c. component of the plate current, so that only the a-c. ripple passed through the galvanometer fiber. When making a measurement the tap of the potentiometer across the filament was moved so as to eliminate the fundamental component (60 cycle) from the Einthoven tracing, leaving practically a pure 120-cycle disturbance. The double amplitude of this disturbance gave the difference between maximum and minimum plate currents, that is $(i_m - i_o)$. The average current i_p as indicated by the milliameter was noted, and from these observations the values of i_m and i_o could be found.

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(6) Corbino: *Phys. Ziet. 11*, 414 (1910).

[7] Jones and Langmuir: General Electric Review, July, 1927, p. 354.

The phase of the ripple was determined as follows: The synchronous timing-wheel of the Einthoven was driven from the same 60-cycle line used for the filament. The shadows of the string and time marker were viewed in a rotating mirror driven at appropriate speed. A shunt circuit was arranged so that a small fraction of the filament current could be sent through the Einthoven and its phase compared with the timing-wheel shadow. The timing-wheel phase then served to fix the phase of the plate current ripple in subsequent observations.

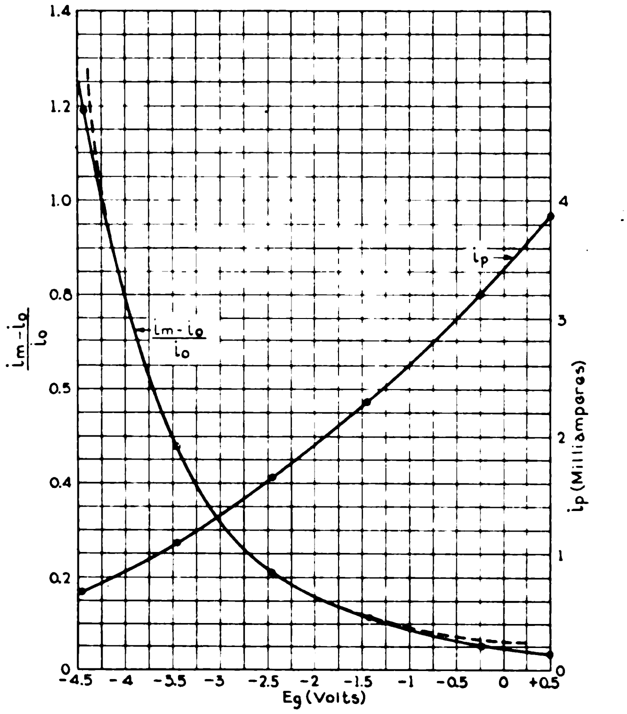

Fig. 5. Calculated (Dashed Curve) and Observed Primary Potential Ripple in the UX 201-A Radiotron

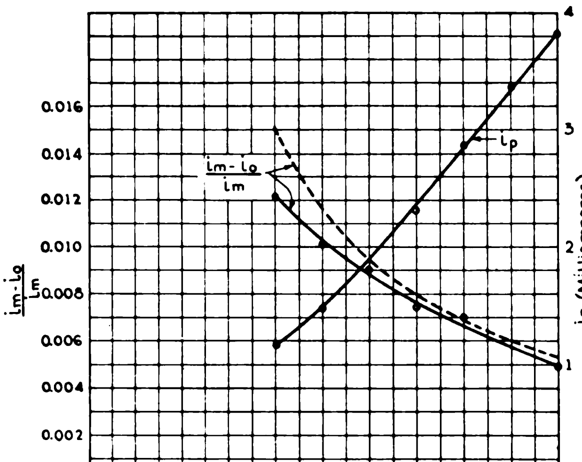

Fig. 6. Calculated (Dashed Curve) and Observed Primary Magnetic Ripple in a Special Tube Having a Very Heavy Filament

Calibration measurements were made to see how the sensitivity of the Einthoven galvanometer varied with the frequency, and with the string tension. The sensitivity at 120 cycles was practically the only one required. Phase lag in the galvanometer deflections at 120 cycles was noticeable, but not serious, particularly as in most cases it was desired only to compare the phases of different 120-cycle ripples.

A good example of primary potential ripple is furnished by the 201-A tube. This is a thoriated filament amplifier tube for which $\mu = 8$, $E_f = 5$, $I_f = 0.25$. In Fig. 5 the curve marked i_p shows the plate current at $E_p = 45$ volts and various values of the grid voltage. The full curve at the left shows the observed values of $(i_m - i_o)/i_o$ for the same grid and plate voltages, the applied grid voltages having been corrected for a contact potential difference of $+0.56$ volts with respect to the filament. The dotted curve shows the calculated values of $(i_m - i_o)/i_o$ taken from the curve of Fig. 2. The curves diverge at the most negative grid voltages probably because the effective anode voltages are so low that the initial velocity of the electrons becomes important. The curves also diverge slightly when the grid becomes sufficiently positive to take up electrons from the filament, because this grid current, owing to the potential drop over the grid potentiometer, gives rise to a secondary potential ripple in the plate current as will be shown in Section VII. This secondary ripple is

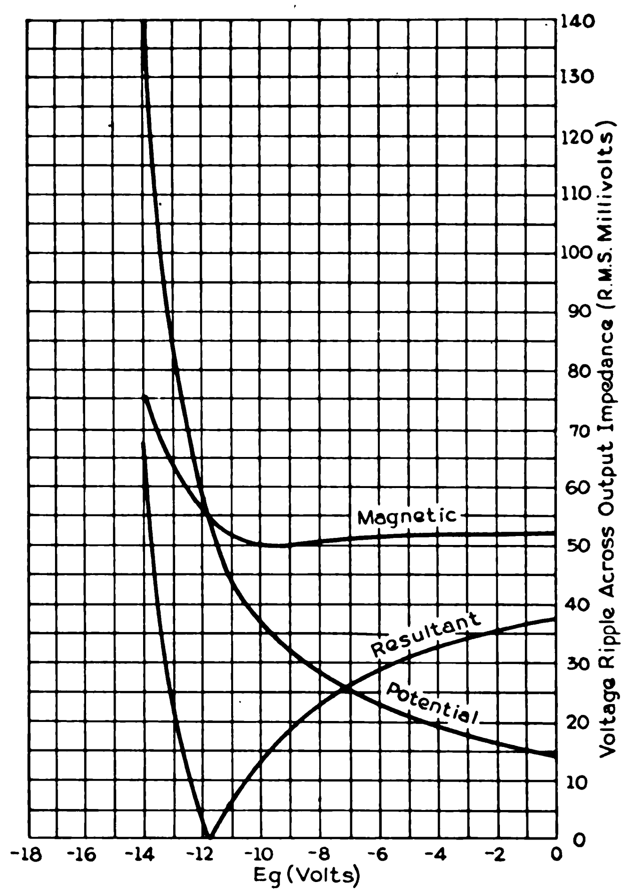

Fig. 7. Calculated Primary Potential and Magnetic Ripples, and Their Resultant, for a UX-226 Radiotron. The ripples are calculated as r.m.s. voltages across an impedance in the anode circuit

180 deg. out of phase with the primary ripple, and therefore is to be subtracted, so that the observed ripple curve lies below the one calculated for the primary potential ripple.

The agreement between observation and theory is however sufficiently good for us to say that the 201-A tube presents a case of practically pure primary potential ripple. The plate current is only a small fraction of the total emission (45 milliamp.) so that the temperature ripple (Section V) is relatively small. The heating current is small enough to make the magnetic ripple (Section III) unimportant. It is also interesting to note that although the filament is V-shaped there is no appreciable "grid action" of one end of the filament on the emission from the other end. No definite cases of such "grid action" have been observed, and the formula developed for primary potential ripple is equally applicable to straight or V-shaped filaments.

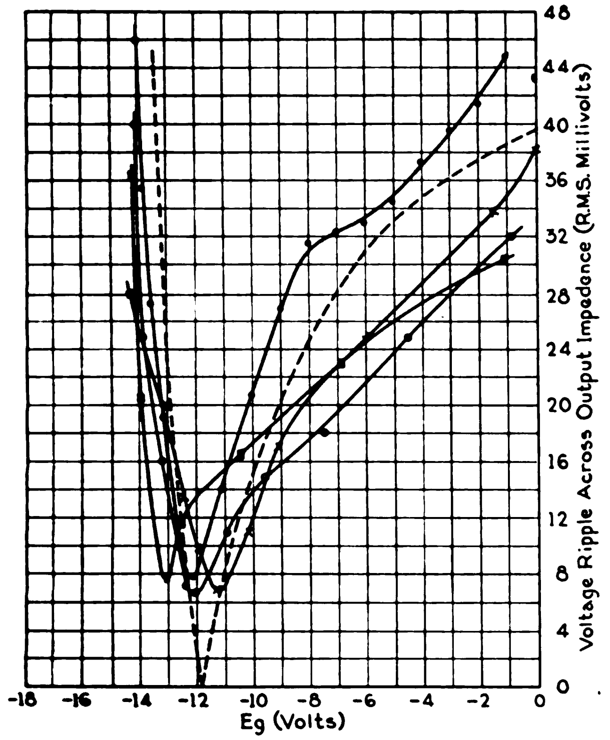

Fig. 8. Comparison of Calculated (Dashed Curve) and Observed Resultant Ripples for UX-226 Radiotron

The observation also showed that the maxima of the primary potential ripple (120 ~) were approximately in phase with the maxima (in both directions) of the 60-cycle heating current. Any slight difference observed is probably to be ascribed to differences in the lag of the Einthoven fibre at 60 and 120 cycles.

Measurements to test the theory of the magnetic ripple were made on a tube having a heavy caesium-coated filament, whose dimensions were so chosen that the entire plate ripple would be due to the magnetic field of the filament. The tube constants were $I_f = 1.5$. amp., $E_f = 0.45$ volt, $\mu = 4.85$, filament radius $r_o = 0.0127$ cm. The radius γ of the equivalent diode was found to be about 0.21 cm.

The results are shown in Fig. 6. The dotted curve shows the calculated values of $(i_m - i_o)/i_m$ and the full curve the observed values. The agreement is satisfactory, considering the uncertainty in determining r. The phase of the ripple was found to be as expected, *i.e.*, the plate current was a maximum when the filament current was zero. The curve marked i_p shows the plate current.

We shall next consider tubes so designed as to make the potential and magnetic ripples of equal importance. In the tubes used, the ratio of grid to filament diameter (r/r_o) was about 21. The filament resistance was approximately 1.5 ohms and μ was 8.0.

We have compared the theoretical curves with a number of ripple characteristics taken from a report by Mr. Rockwood of this Laboratory. In these measurements an impedance R (26,000 ohms at 120 cycles) was connected in the anode circuit, and the r.m.s. ripple voltage set up across this was amplified and measured. Our formulas give the double amplitude of the ripple, and assume no impedance in the circuit other than the plate impedance of the tube itself (r_p). The r.m.s. value of the ripple voltage across the impedance R will therefore be

$$\frac{i_m - i_o}{2\sqrt{2}}\;\frac{r_p R}{R + r_p}$$

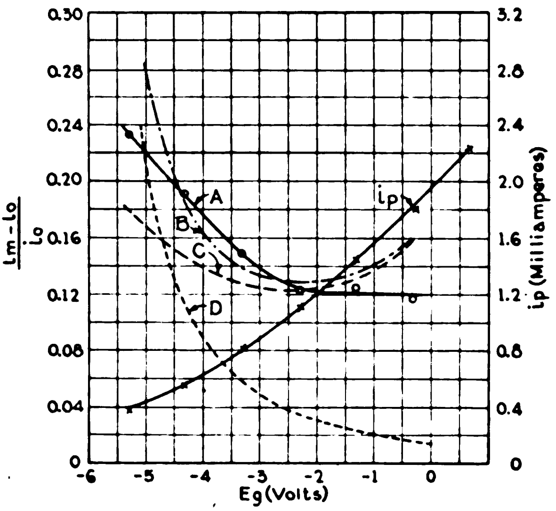

Fig. 9. Primary Temperature and Potential Ripples in the UX-199 Radiotron

The measurements were made at $E_p = 135$ volts and various grid voltages. The value of r_p for a typical tube at $E_p = 135, E_g = -11$ was 7500 ohms. Fig. 7 shows the calculated curves for the magnetic and potential ripple voltages, and for their resultant. As the grid is gradually made more negative the resultant ripple falls to zero at -11.8 volts, and its phase changes from magnetic to potential. This change of phase has been checked by measurements with the Einthoven galvanometer. Variations in these curves arising from slight unavoidable differences in μ and r_p for different tubes, are small; apparently much greater variations in ripple are due to eccentricity of the filament, and other structural irregularities.

Fig. 8 shows the experimental ripple curves for a number of tubes of normal characteristics. The theoretical curve from Fig. 7 is dotted in for comparison, and its zero point agrees well with the minima of the experimental curves.

A good example of temperature ripple is supplied by the UX-199 Radiotron. This tube has a thoriated tungsten filament of about 0.0015 cm. diameter. The active part of the filament was assumed to be 1.5 cm. long. The constants required are (see Section V) $T_m = 1925$ deg. K, $f(T_m) = 0.141$ watt, $C = 9.11 \times 10^{-6}$ joule per deg., $a = 6.25 \times 10^{-4}$, $\omega = 2\pi \times 60 = 377$, $\beta = 4.99$. Hence $\phi = 86$ deg., $\theta_0 = 21$ deg. temp. That is, the filament temperature fluctuates between 1946 and 1904 deg. K, on a 120-cycle wave, and the temperature maxima lag 86 deg. in phase behind the maxima and minima of the 60-cycle heating current.

Fig. 9 shows the plate current i_p in a UX-199 Radiotron as a function of E_g for $E_p = 45$, $E_f = 3$. The grid voltages have been corrected by adding a contact potential of +0.68 volts with respect to the filament. The potentiometer across the filament was adjusted to eliminate the 60-cycle component of the plate ripple. Curve *A* of this figure shows the residual 120-cycle ripple as a fraction of i_0 the minimum plate current. The phase of this ripple lagged about 90 deg. (of 120 cycles) behind the filament current, for grid voltages near zero. The ripple under these conditions was therefore due mainly to a temperature effect. When the grid was made quite negative the phase advanced towards that appropriate to a primary potential ripple, *i.e.*, in phase with the filament current.

The filament was then run on d.c. and the plate currents noted at various grid voltages for filament temperatures of 1946 and 1904 deg. K, which are the calculated maximum and minimum temperatures attained in a-c. operation. Curve *C* of Fig. 9 shows values of $(i_m - i_0)/i_0$ obtained from these data.

Curve *D* gives the potential ripple calculated as in Section II for $E_f = 3$, $E_p = 45$, $\mu = 6.5$. The ripples represented by *C* and *D* are almost 90 deg. out of phase with each other, so that the square root of the sum of their squares was taken as giving their resultant, and is shown in Curve *B*. The agreement with Curve *A* is only rough, probably for the following reasons. At the more negative grid voltages changes in μ and effects due to the emission velocities of the electrons become important. In the temperature ripple calculation no allowance was made for the cooling effect of the leads on the ends of the filament. The change in temperature of the cooled ends would be greater on the d-c. test (Curve *C*) than on the a-c. test, and the effect on the plate current would be greater near $E_g = 0$, for there the emission from the cooled parts would be nearer saturation. Hence Curve *C* lies above Curve *A* near $E_g = 0$.

(To be continued)

Ornamental Street Lighting Units on Wilshire Boulevard, Los Angeles (Calif.)

An Accuracy Test for Flux Plotting Methods

Fundamental Considerations—Usefulness of Free-hand Plots—Calculation of a Typical Case—Comparison of Results—Derivation of General Equations

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THE process of making flux plots constitutes an extremely useful tool for the solution of some magnetic and electrical problems. The flux plots are made by drawing series of lines of flow and equipotential lines, which cross each other at right angles. In flux plotting, the lines are usually drawn to a considerable extent free-hand, the work being guided by two main rules, *viz.*, that the lines shall cross each other at right angles; and that the figures so formed shall be curvilinear squares, *i.e.*, they shall each have two equal diameters. These considerations are in evidence in Fig. 1. The reason for using curvilinear squares instead of rectangles is that it is comparatively easy to test for equal diameters, either by measurement or by estimating by eye. The diameters are taken as the distances between the middle points of opposite sides. Additional rules have been described in technical articles and textbooks. (1)

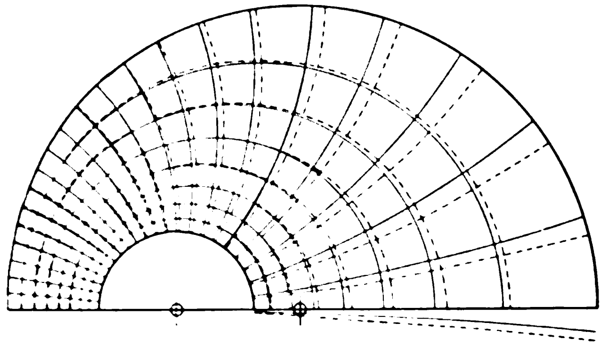

Fig. 1. A Comparison of the Free-hand and the Calculated Flux Plots for Two Circles. The dotted lines are the free-hand, and the full lines the calculated plots

Since considerable interest is taken at the present time in the free-hand plotting of equipotential lines and lines of flow, the following quotation from Maxwell, (2) referring to the forms of equipotential surfaces and lines of induction, may be of interest:

> "In certain classes of cases, such as those relating to spheres, there are known mathematical methods by which we may proceed. In other cases we can not afford to despise the humbler method of actually drawing tentative figures on paper, and selecting that which appears least unlike the figure we require.
>
> "This latter method I think may be of some use, even in cases in which the exact solution has been obtained, for I find that an eye-knowledge of the forms of the equipotential surfaces often leads to a right selection of a mathematical method of solution."

In order to enable anyone to test the accuracy of making flux plots according to the free-hand method, it is useful to have a type of problem for which all the lines can be calculated. If the lines are all circles, they can be easily drawn. These conditions are met by the problem of drawing a flux plot between two equal or unequal circles. Considerable variety in the maps of flux lines may be obtained, since the two circles can have various proportions and separations, and one can lie inside or outside the other.

By drawing a free-hand map by flux plotting rules, and then drawing on it the circles of calculated size and position as in Fig. 1, not only can the value of total flux be checked, but the correctness of every line in the flux plot can be quickly determined. Valuable practice in judging what are accurate right angles and curvilinear squares may be obtaind by examining the calculated flux plot.

The mere equations of the families of circles as usually published are not sufficient information to draw the field map in curvilinear squares between two given conductors, but additional information is required, as given in this article.

Let the radii of the two circles chosen be a and b and the distance between their centers be c (see Figs. 2 and 3). Let p be the number of squares in the calculated flux plot measured along the equipotential lines, and let f be the number of squares measured along the lines of flow. The problem may be considered to be the electrostatic problem of calculating the capacitance between two cylinders, of which the circles are sections. The flux plot will be the same for any other kind of flow. The capacitance is given in terms of p and f in a manner similar to that for two parallel plates.

Thus, the capacitance is given by two expressions which can be equated:

$$\frac{1}{4\pi}\frac{p}{f}=\frac{1}{2\log_e(\beta+\sqrt{\beta^2-1})} \tag{1}$$

where, when one circle does not enclose the other,

$$\beta=\frac{c^2-a^2-b^2}{2ab} \tag{2}$$

and where, when one circle encloses the other (3)

$$\beta=\frac{a^2+b^2-c^2}{2ab} \tag{3}$$

The circles should not cut each other. The number f may be assumed and p calculated from Equation (1), or p may be assumed and f calculated. The ratio of p and f will then be such as to give curvilinear squares.

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(1) See, for example, "Graphical Determination of Magnetic Fields," by A. R. Stevenson, Jr., and R. H. Park, GENERAL ELECTRIC REVIEW, February and March, 1928; or A. D. Moore: *Fundamentals of Electrical Design*, Chapters IV to IX.

(2) J. C. Maxwell: *Electricity and Magnetism*, Vol. 1 (1873), Article 117.

(3) Alex. Russell: *Alternating Currents*, Vol. 1 (1904), pp. 102 and 104.

Find
$$d^2 = \frac{a^2b^2}{c^2}(\beta^2 - 1) \tag{4}$$

The length $2d$ is the distance between the two concentrated charges which would produce the same field as the charges on the two cylinders. Let these charges be of value q and $-q$ and the potentials of the two circles be V_1 and V_2.

Find
$$\frac{V_1}{2q} = \log_e\left(\frac{\sqrt{d^2+a^2}+d}{a}\right) \tag{5}$$

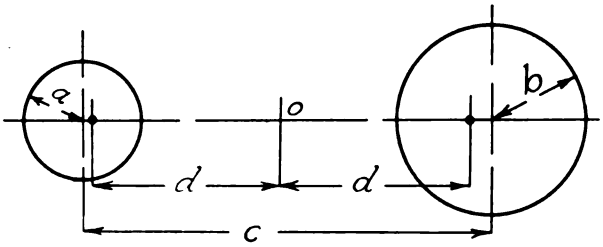

Fig. 2. A Diagram Showing the Dimensions Used in Calculating the Flux Distribution for Two Circles in Their "Non-enclosing" Relationship

If one circle does not enclose the other,
$$\frac{V_2}{2q} = \log_e\left(\frac{\sqrt{d^2+b^2}-d}{b}\right) \tag{6}$$

If one circle encloses the other,
$$\frac{V_2}{2q} = \log_e\left(\frac{\sqrt{d^2+b^2}+d}{b}\right) \tag{7}$$

Divide the quantity $\frac{V_1}{2q} - \frac{V_2}{2q}$ into f parts, and let $\frac{V}{2q}$ be any one of the dividing values so obtained. The radius of the corresponding equipotential circle is
$$r = \pm \frac{2\,d\,e^{\frac{V}{2q}}}{1 - e^{\frac{V}{q}}} \tag{8}$$
the positive value of r being taken.

If a table of natural logarithms is not at hand and it is desired to compute more accurately than by slide rule, the following procedure can be used:

Find
$$\log_{10}\left(\frac{\sqrt{d^2+a^2}+d}{a}\right)$$
and a corresponding logarithm for the other circle (see Equations 6 or 7). Divide the difference between the logarithms into f parts. The anti-logarithm of one of the intermediate values will be
$$10^{0.434\frac{V}{2q}} = e^{\frac{V}{2q}}$$
the value of which is required in Equation (8). The table of logarithms to base 10 can thus be used directly, without multiplying any quantities by 0.434.

The center of the equipotential circle of radius r is on the axis of x, at a distance from the center of the circle of radius a equal to
$$\sqrt{d^2+r^2} + \sqrt{d^2+a^2} \tag{9}$$
when V_1 and V are of opposite sign,

and
$$\sqrt{d^2+r^2} - \sqrt{d^2+a^2} \tag{10}$$
when V_1 and V are of the same sign. This distance is to be measured in a direction such as will make the centers of the equipotential circles lie outside the centers of the two given circles, when one of the latter does not enclose the other, and to make a circle of radius r enclose a given circle of the same polarity. When one of the given circles encloses the other, the distance is to be measured in a direction making the centers of the equipotential circles lie between the centers of the two given circles.

The flow lines are circles whose centers are on the line which is perpendicular to the line of centers of the given circles and which passes through the point of zero potential, on that line. This point of zero potential is at a distance $\sqrt{d^2 + a^2}$ from the center of the circle of radius a, and at a distance $\sqrt{d^2 + b^2}$ from the center of the circle of radius b. The center of the nth circle of flow is at a distance from the X-axis equal to
$$d \cot \frac{2\,n\,\pi}{p} \tag{11}$$
and the radius is
$$\frac{d}{\sin \frac{2\,n\,\pi}{p}} \tag{12}$$

The flow-line circles all pass through the two inverse points, at a distance $2d$ apart, where equal and opposite concentrated charges will give the same flux map as that of the two given circles. The angles between the tangents to the flow circles at these points are proportional to the amounts of flux between the corresponding flux lines.

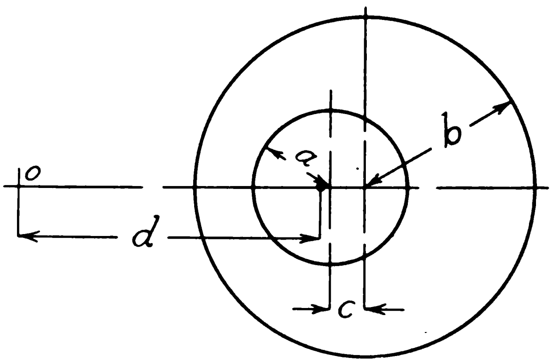

Fig. 3. The Dimensions Used in Calculating the Flux Plot for the "Enclosing" Relationship of Two Circles

Example: (See Fig. 1.)

$a = 5.1$ cm. $b = 19.85$ cm. $c = 8.2$ cm.

$\beta = 1.742$

$\log_e(\beta + \sqrt{\beta^2 - 1}) = 1.153$

$\frac{p}{f}$, calculated $= \frac{4\pi}{2 \times 1.153} = 5.45$

$\frac{p}{f}$, by free-hand plot $= \frac{43.3}{8} = 5.41$

Discrepancy 0.7 per cent.

It may be mentioned that a larger discrepancy may reasonably be expected, especially for the case of two separate circles. It is found that the free-hand method can give either too large or too small a result, measured in total capacitance or in number of squares.

The writers desire to express their acknowledgment to Dr. H. B. Dwight of the Massachusetts Institute of Technology at whose suggestion this work was done. A considerable part of the material in this article was given by the writers in a paper before the Student Convention of the A.I.E.E. at New Haven (Conn.) in May, 1928.

APPENDIX

The equations in this article may be derived by the method of "comformal mapping" which is a powerful tool in the calculation of orthogonal families of curves, such as equipotential and flow lines. Two families of curves are orthogonal when they cut each other always at right angles.

Two families of straight lines represented by $u=$ a constant and $v=$ a constant are drawn in a plane called the W-plane. A function

$$w=f(z)$$

is chosen, where

$$w=u+jv$$

and

$$z=x+jv$$

Then u and v are each functions of x and y and when u is put equal to a constant, x and y can be plotted to give a curve in another portion of paper called the Z-plane.

While the lines on the Z-plane are quite different in appearance from those on the W-plane, it can be proved that the angle between two short intersecting lines is the same in one plane as in the other, and the magnification of the length of each line is the same. If the straight lines on the W-plane form squares, the lines on the Z-plane will form curvilinear squares. The latter will have all their angles right angles (except at certain exceptional points). The diameters will be practically equal, especially when the squares are not large.

The shape of the resulting curves is determined, of course, by the particular function $f(z)$ chosen. Various functions have been tried and the resulting curves studied. In the case of two charged circular cylinders it is known that the value of the potential is a logarithmic function, thus suggesting the use of a logarithmic relation between w and z. It was found that the equipotential lines and lines of flow are given(4) by the function

$$w=\frac{1}{2\pi}\log_e\frac{z-d}{z+d} \qquad (13)$$

in which

$$z=x+jy$$

and

$$w=\frac{V_1-V_2}{4\pi qf}+j\frac{n}{p}$$

or

$$=\frac{V}{4\pi q}+j\frac{n}{p}$$

where the letters have the meanings given in the article.

$$\frac{V}{4\pi q}+j\frac{n}{p}=\frac{1}{2\pi}\log_e\frac{x+jy-d}{x+jy+d}$$

$$=\frac{1}{4\pi}\log_e\frac{(x-d)^2+y^2}{(x+d)^2+y^2}+\frac{j}{2\pi}\left(\tan^{-1}\frac{y}{x-d}-\tan^{1}\frac{y}{x+d}\right) \qquad (14)$$

Equating the real parts, and reducing to an equation in x and y,

$$\left[x-d\left(\frac{1+e^{\frac{V}{q}}}{1-e^{\frac{V}{q}}}\right)\right]^2+y^2=d^2\left[\frac{2e^{\frac{V}{2q}}}{1-e^{\frac{V}{q}}}\right]^2$$

This is the equation of an equipotential circle, the radius of which is seen to be given by Equation (8). The coördinates of the center reduce to

$$x=\sqrt{d^2+r^2} \quad \text{and } y=0$$

Changing the origin to the center of one of the given circles, Equations (9) and (10) are obtained.

Equating the imaginary parts of Equation (14) and making use of the expression for tan (A-B),

$$x^2+\left(y-d\cot\frac{2n\pi}{p}\right)^2=\frac{d^2}{\sin^2\frac{2n\pi}{p}}$$

This is the equation of a flow-line circle, whose center and radius are seen to be given by Equations (11) and (12).

It is necessary to find the value of d from the given dimensions. When one circle encloses the other, the distance between the centers of the circular conductors is

$$c=\sqrt{(d^2+a^2)}-\sqrt{(d^2+b^2)}$$

Then

$$c^2=2d^2+a^2+b^2-2\sqrt{(d^4+a^2d^2+b^2d^2+a^2b^2)}$$

$$4(d^4+a^2d^2+b^2d^2+a^2b^2)=(2d^2+a^2+b^2-c^2)^2$$

$$4d^2c^2=(a^2+b^2-c^2)^2-4a^2b^2$$

which gives Equation (4) for d^2. The same expression for d^2 is obtained when one circle does not enclose the other.

An alternative method of calculating the field between two circular cylinders is to make use of the fact that the field is the same as for two infinitesimal wires at a distance $2d$ apart. There are other problems, however, which cannot be solved by assuming concentrated charges in this way, and for them the more powerful method of conformal mapping is required. For instance, the latter method was used by Dr. F. W. Carter in determining the well-known "Carter's coefficient" for the effect of the magnetic field in armature slots of electric machines.

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(4) E. J. Townsend: *Functions of a Complex Variable*, p. 138.

Specifications for Welding Steel Buildings by Electricity

General Applications—Definitions—Materials—Apparatus—Permissible Unit Stresses—Workmanship—Qualification of Welders—Proportion of Parts—Protection of Steel

Prepared by
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Section 1: GENERAL APPLICATION

(*a*). Arc welding may be substituted for or used in connection with rivets or bolts, or other methods prescribed in the Standard Specifications for Structural Steel for Buildings adopted by the American Institute of Steel Construction as amended to date, for connecting together or assembling the component parts of beams, girders, lintels, trusses, columns, or other structural steel used in building construction.

Section 2: DEFINITIONS

(*a*). Arc Welding

The process of using the electric arc to join steel parts in the molten, or molten and vapor states, without the application of mechanical pressure or blows.

(*b*). Arc Weld

A weld in which the welding heat is generated by an electric arc formed between the base metal and the electrode, or between two electrodes, with or without the use of hydrogen or other equivalent gas.

(*c*). Electrode

A specially prepared metal wire or rod used as a terminal in an electric circuit to produce an intense heat by means of the arc, and which may or may not supply the molten steel required for joining the parts to be welded.

(*d*). Filler Metal

The metal which is added to a weld by the melting of an electrode or a welding rod.

(*e*). Weld Metal

The material composing a weld.

(*f*). Base or Parent Metal

The material to be welded.

(*g*). Fillet Weld

A weld, at the intersection of two surfaces approximately at right angles to each other, in which the weld metal has a triangular cross-section, its two sides being the original surfaces of the base metals, and its third side the exposed hypothenuse.

The size of a fillet weld is expressed in terms of its length and width, the latter being the dimension of the side of the largest isosceles triangle contained in the cross-section of the weld metal.

(*h*). Butt Weld

A weld joining the edges of a butt joint in which two members are brought together edge to edge but not necessarily in contact, one surface of each member being in the same or parallel planes.

(*i*). Continuous Weld

A weld of unbroken continuity used for strength or tightness, or both.

(*j*). Intermittent Weld

A strength weld consisting of a series of short welds in line, alternating with unwelded spaces.

(*k*). Tack Weld

A short weld used not for strength but for purposes of assembling only.

Section 3: QUALITY OF MATERIALS

(*a*). Structural Steel

The steel used in structures covered by these specifications shall be of the grade designated as "Structural Steel for Buildings," as specified by American Society for Testing Materials, Serial No. A9, as amended to date.

(*b*). Electrodes and Welding Rods

The wire used for electrodes, or the welding rods, shall be commercial mild-steel wire made for this purpose, of uniform homogenous physical structure, and free from irregularities in surface, from hardness, segregation, foreign matter, oxides, pipes, seams, or other defects.

Welding wire made from steel produced by the puddling process shall not be used.

The diameter shall not vary more than 0.003 in. above or below the nominal values.

In the hands of an experienced welder, electrodes and welding rods shall show good welding qualities in flat, vertical, or overhead positions, and shall pass through the welding process without exhibiting any unusual characteristics.

The chemical compositions shall conform to the limits given in Table I for uses specified.

Wire of Grade A shall be used for hand arc welding; and Grade B for automatic machine arc welding.

Section 4: APPARATUS

(*a*). The arc-welding apparatus shall be of standard design and be the product of a reputable manufacturer.

(*b*). The welding current shall preferably be direct current supplied by generators driven by electric motors or engines having suitable automatic speed regulation. Whether for use in hand or machine welding, the generators shall be adjustable for different current values and shall deliver constant current at suitable voltage for each setting of the regulator.

Section 5: PERMISSIBLE UNIT STRESSES

(*a*). The welded joints shall be so proportioned that the combined dead and live loads, and impact, if any, shall not cause the stresses therein to exceed the following amounts in ***pounds per square inch:***

Shear on minimum section of weld metal	11,300
Tension of minimum section of weld metal	13,000
Compression of minimum section of weld metal	15,000

(*b*). The maximum fibre stresses due to bending shall not exceed the values prescribed in paragraph (*a*) for tension and compression respectively.

(*c*). The stresses in welded joints due to wind only, and combined stresses due to wind and other loadings, may exceed by 33⅓ per cent the values prescribed in paragraph (*a*); provided the section thus obtained is not less than that obtained if the wind force be neglected.

(*d*). In designing welded connections allowance shall be made for bending stresses due to eccentricity, if any, except that in designing fillet welds no allowance need be made for the bending couple formed by resultant stresses on the two fused sides of the weld.

TABLE I

	Wire, Grade A Per Cent	Wire, Grade B Per Cent
Carbon	0.13 to 0.18	Not over 0.10
Manganese	0.40 to 0.60	0.25 to 0.45
Phosphorus	Not over 0.015	Not over 0.015
Sulphur	Not over 0.015	Not over 0.015
Silicon	Not over 0.06	Trace

Section 6: WORKMANSHIP

(*a*). The surfaces to be welded shall be reasonably cleaned of loose scale, rust, paint, or other foreign matter by wirebrushing, chipping, or hammering; except that a thin coat of linseed oil need not be removed before welding.

(*b*). The welding operators shall submit evidence of experience in welding structural steel with the kind of welding to be used on the proposed work, and show ability to make flat, vertical, and overhead welds of uniform quality conforming to the requirements of these specifications.

(*c*). After being laid, the welds shall be brushed with wire brushes, and shall show uniform sections, smoothness of weld metal, feather edges without overlaps, and freedom from porosity and clinkers. Visual inspection at the edges and ends of fillet-joint and butt-joint welds shall indicate good fusion with and penetration into the base metal.

(*d*). The arcs for electric welding shall be of proper lengths to produce good welds.

The same electrode may be used with various thicknesses of plate, but thicker plates require heavier currents.

(*e*). The current values to be used in hand welding are indicated approximately by the figures shown in Table II, which are intended as a guide to the operator who shall select the size of electrode and then adjust the electric current to produce good homogeneous welds of the foregoing characteristics.

TABLE II

Electrode Diameter in Inches	Ampere for Hand Welding	Corresponding Plate Thickness in Inches
$\frac{1}{16}$	50 to 75	Up to $\frac{3}{16}$
$\frac{3}{32}$	75 to 100	Up to $\frac{1}{4}$
$\frac{1}{8}$	100 to 150	Above $\frac{1}{8}$
$\frac{5}{32}$	150 to 200	Above $\frac{1}{4}$
$\frac{3}{16}$	175 to 225	Above $\frac{3}{8}$
$\frac{1}{4}$	200 to 250	Above $\frac{3}{8}$

(*f*). The current values for machine welding may exceed those specified in paragraph (*e*), but machine welding shall, if required, meet the same qualifications as specified for welders in Section 7.

(*g*). In assembling and during welding, the component parts of built-up members shall be held by sufficient clamps or other adequate means to keep the parts straight and in close contact.

(*h*). In welding, precautions shall be taken to minimize "locked-up" stresses and distortion due to heat.

(*i*). Before welding new steel to old, both shall be free from paint and other foreign matter, except that a thin coat of linseed oil need not be removed.

Section 7: QUALIFICATIONS OF WELDERS

(*a*). Butt Welds

The welders may be required to weld four sample butt joints each made of two pieces ½ in. by 9 in. by 12 in. to form a piece about 12 in. by 18 in., prepared with double Vee as specified in Section 8, paragraph (*f*); of these, two sample plates are to be welded in the horizontal or flat position and two in the vertical position with the joint located vertically.

Each sample plate shall be machined so that the joint is reduced to the thickness of the base metal. From each sample plate, standard two-inch tensile-test specimens shall be made and tested in tension, to conform with the American Welding Society standards. The average tensile strength of each group of five sample plates shall not be less than 45,000 lb. per sq. in., and the tensile strength of the lowest in each group shall not be less than 40,000 lb. per sq. in.

(*b*). Lap Welds

The welders may be required to weld four sample lap joints each made of ½-in. by 6-in. by 8-in. plates clamped one on the other with the 8-in. edges lined up but with the 6-in. edges offset ½ in. A full ½-in. fillet is then to be made along one 6-in. edge in accordance with the specifications presented in Section 8, paragraph (*g*).

Upon completion of the welds and after cooling, the specimens shall be torn apart and broken by wedging at the unwelded 6-in. edges; and the fractured metal of the specimen broken through the weld shall reasonably show: bright, dense, even-textured, crystalline or fibrous weld metal, irregularly torn and void of iridescent colors; good fusion of weld and base metals; and good penetration into right-angle corner of the fillet.

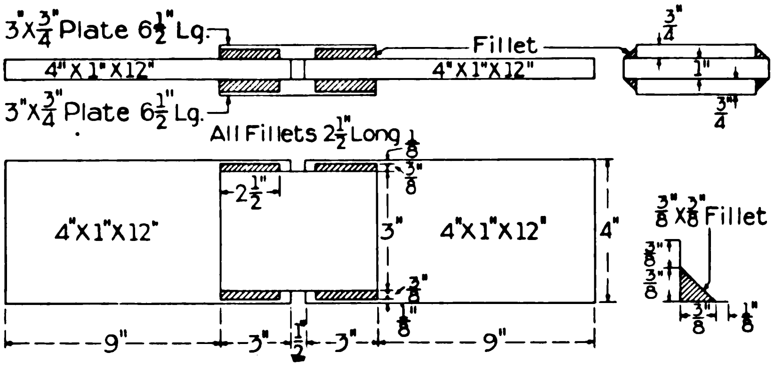

Fig. 1. Test Specimen for Fillet Weld

(*c*). Fillet Welds

The welders may be required to weld three sample test specimens of the size shown in Fig. 1. In depositing the weld metal, all craters shall be filled to the full cross-section of the fillets. Electrodes of $\frac{3}{16}$-in. diameter shall be used. These specimens are to be tested in tension to ascertain the longitudinal shearing value of the ⅜-in fillet welds, and the fractured specimens shall be examined for penetration into the parent metals and for freedom of gas holes or slag inclusions in the fillets. The three specimens shall show at least an average ultimate longitudinal stress of 38,000 lb. per sq. in. and the lowest in the group shall show at least 34,000 lb. per sq. in. of minimum section of fillet.

Section 8: PROPORTION OF PARTS

(*a*). Plate Girders

Girders shall preferably be proportioned by their moments of inertia, but where the approximate method of flange design is used the web equivalent may be taken as one-sixth of the web area, provided no holes exist in the web.

The web splices shall consist of a plate on each side of the web.

The stiffeners may be angles or flat bars, welded to the top and bottom flanges and also to the web by continuous or intermittent welds designed to transmit the stresses. The stiffeners at the bearings or other points of concentrated loading shall be fitted to the flanges.

The connection of component parts of girder flanges to each other and of flanges to webs shall be by continuous or intermittent fillet welds designed to transmit the stresses. Intermittent welds shall be not less than one and one-half inches long, spaced in the clear not exceeding 16 times the thickness of the thinnest piece connected, nor more than four inches in the clear.

Plug or slot welds may be used to fasten cover plates to other members.

(*b*). Beams

Continuous beams and girders designed in accordance with generally accepted engineering principles may be used, provided that welded connections be properly proportioned to resist bending moments to which they are subjected.

When the toe of a seat angle supporting a beam is to be welded to a web or to a column and is not truly formed, but is rounded due to worn rolls or other causes, either a preliminary fillet shall be deposited to fill the open space after which the full fillet required in the design shall be deposited, or the rounded edge of the toe shall be sheared square to receive the full fillet required.

(*c*). Trusses

For tension or compression members having symmetrical cross-sections, the fillets shall be arranged symmetrically about the axis of the member, or proper allowance shall be made for unsymmetrical distribution.

For members of unsymmetrical cross-section, like angles for example, the lengths of fillets shall be determined by taking moments about the gravity axis of the member.

(*d*). Columns

Built-up or rolled-steel columns shall contain no material, except filler plates, whether in the body of the column or used as lattice bars or stay plates, less than ¼ in. in thickness.

The ends of columns shall be faced to plane surfaces at right angles to their axes. Column splices, whenever practicable, shall consist of splice plates connected to the columns with proper amounts of fillets. When sections of columns to be spliced are such that splice plates cannot be used, connections may be formed of plates and angles or other shapes designed to distribute the stresses properly. In all cases, column splices shall be so arranged that by bolts or otherwise the various tiers of a column can be accurately aligned before welding, and shall be of sufficient strength to carry the erection stresses.

The fillets connecting component parts of a built-up column may be either continuous or intermittent, and if of the latter type shall be arranged as follows: Continuous fillets extending at each end of the column for a distance equal to the least width of the column; then intermittent fillets one and one-half inches long spaced not exceeding four inches in the clear for the remainder of the column's length.

Lattice bars and tie plates, where used, shall be welded with fillets to secure strengths equal to those of the rivets in lattice bars and tie plates connected by rivets as specified in the Standard Specifications for Structural Steel for Buildings adopted by the American Institute of Steel Construction and as amended to date.

(*e*). Welding and Bolting

For welding structures, connections of main members carrying live loads producing impact, and connections of members subject to alternate stresses, shall be welded.

For welded structures, component parts of all columns, girders, and trusses shall be welded with fillet welds.

For welded buildings over four stories high, all column splices and all connections of beams and girders to columns—or within three feet thereof—shall be welded.

Unfinished bolts may be used in the shop or field for connections of small structures used for shelters and for connections of secondary members of all structures, such as purlins, girts, door and window framing, lining up bracing, and filling-in beams in floors. In buildings two or more stories high, sufficient bolts shall be used to connect properly all members during erection.

So far as possible all joints shall be designed to eliminate overhead welding, and arranged so that the welds will be in shear or direct compression.

Tension butt welds shall not be used in main truss members, but may be used in secondary members, wind bracing connections, beam and girder connections.

To the calculated lengths of each weld, proper additions shall be made to allow for the crater.

Fillet welds of lengths less than four times their width shall not be figured as part of any connection.

(*f*). Butt Joints

All portions of members ¼ in. in thickness, or over, to form butt joints shall be beveled with either single Vee or double Vee, or their equivalents.

The steel for single Vee joints shall be beveled not less than 30 deg. on each edge to form an open angle of not less than 60 deg.

The steel for double Vee joints shall be beveled not less than 37½ deg. on each side of each piece to form open angles of not less than 75 deg.

In all single Vee and double Vee butt joints the beveled edges shall have initial free distances of ⅛ to 3/16 in.; and steel ¼ to 7/16 in. thick shall be welded in one layer, steel ½ to 11/16 in. in two layers, and ¾ to 1 in. in three layers.

All these joints shall be somewhat reinforced but not to exceed 20 per cent for single Vee or 15 per cent for each side of double Vee joints.

(*g*). Lap Joints

All lap joints in ¼ to 7/16-in. steel shall be fillet welded in one layer, ½ to 11/16 in. in two layers, and ¾ to 1 in. in three layers. The contour of the cross-section of the fillet shall be as near as practicable to a right triangle with equal sides, and with minimum side not less than the prescribed dimension of the cross-section of the fillet.

(*h*). Drawings

The drawings shall show clearly all welds, including the length and width of all fillets both for shop and field welding.

Section 9: PROTECTION OF STEEL

(*a*). The structural steel before being welded shall not be painted. If it is to be welded only in the fabricating shop and subsequently erected by bolts or rivets, it shall receive in the shop one coat of acceptable metal protection after shop welding is finished, and one coat after erection. The steel to be field welded shall receive one coat of linseed oil after shop welding is completed; and after being erected and welded it shall receive two coats of acceptable metal protection.

No paint shall be applied to steel surfaces which are to be encased in concrete.

CREDIT: When publishing the article "Motion Picture Photography with Mazda Lamps," by Messrs. Egeler and Farnham, in our December, 1928, issue, we overlooked acknowledging the fact that it was based on a paper of the same title which had been presented by Mr. Farnham before the Society of Motion Picture Engineers, at Hollywood (Calif.), April 12, 1928.

Oil-immersed Current-limiting Reactors

By F. H. KIERSTEAD
General Transformer Engineering Dept., Pittsfield Works
General Electric Company

THE growth of interconnection between high-voltage lines created a demand for high-voltage reactors to relieve the circuit breakers from the increased duty resulting from this interconnection. A response to this demand was the development of a current-limiting reactor with a magnetic circuit of non-magnetic material assembled in a steel tank and immersed in oil. Such reactors were first used in an outdoor installation made in 1922. No others followed until 1926, but since that date there has been an ever-increasing demand for them.

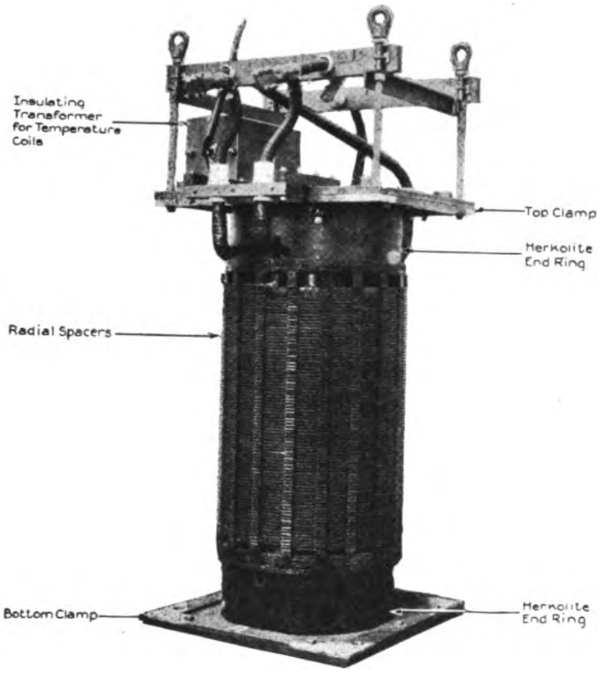

Fig. 1. Interior of a 60-cycle 2750-kv-a. Oil-immersed Reactor for Sectionalizing the 22,000-volt Bus of a Generating Station Having an Ultimate Capacity of 1,000,000 Kv-a.

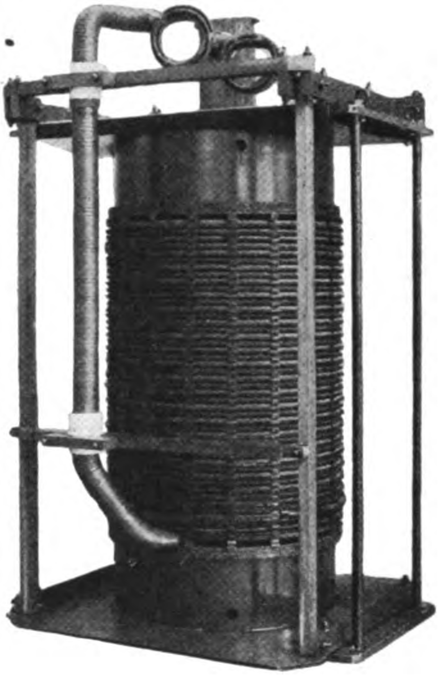

Fig. 2. Interior of a 60-cycle, 2800-kv-a. Reactor for Sectionalizing a 120,000-volt Bus of a Generating Station Having a Capacity of 300,000 Kv-a.

Necessity for Oil-immersed Reactors

The large stations built today are superpower stations compared with those built in the past; and the havoc resulting from a short circuit on the bus of one of these newer stations would be many times greater than that due to a bus failure in one of the older stations. Thus, with the creation of these superpower stations there arose a need for reactors that are secure against every contingency of failure. The "cast-in-concrete" reactor with asbestos-insulated conductor is protected from the probable causes of failure, but, like the bus bars of the station to which it is connected, it depends on porcelain and air spaces for the major insulation between itself and ground. It is therefore desirable to use barriers to protect the reactor (as well as the bus bars) from the accidental bridging of these air spaces that insulate the live parts from ground.

These barriers are customarily obtained by placing both the reactors and bus bars in masonry cellular structure. The cells form very good protection, but because of the necessary ventilating openings, doors, etc., they are not absolutely effective against conducting gases, falling material, prowling animals, and the actions of thoughtless men. One hundred per cent protection from these external causes of failure, however, can be obtained by placing the reactor, immersed in oil, in a steel tank.

Thus it happens that the reactor that was developed in 1922 to meet the exigencies of high-voltage interconnection is just what is needed to meet the ultra-conservative requirement of superpower stations. Where the circuits to and from the reactors are underground cables, the lead sheaths of the cables make wiped joints with glands bolted to the tank so that absolutely all exposed parts are at ground potential.

Obviously it is just as safe to install metal-enclosed oil-immersed reactors outdoors as indoors; and in many installations, part, if not all, of the additional cost of oil-immersed reactors will be compensated by the reduced cost of station buildings.

Even though circuits are inconveniently arranged for installing the reactors out of doors, the use of oil-immersed reactors will often effect an economy which is due to the elimination of cell construction and bracing between units. Their use may also save space since only mechanical clearances are required between adjacent reactors and between reactors and adjacent structural steel or masonry.

Windings.

The windings are of the standard circular coil construction used in transformers and are insulated to stand a voltage of 2¼ times the line voltage plus 2000, which is the usual test for protective apparatus.

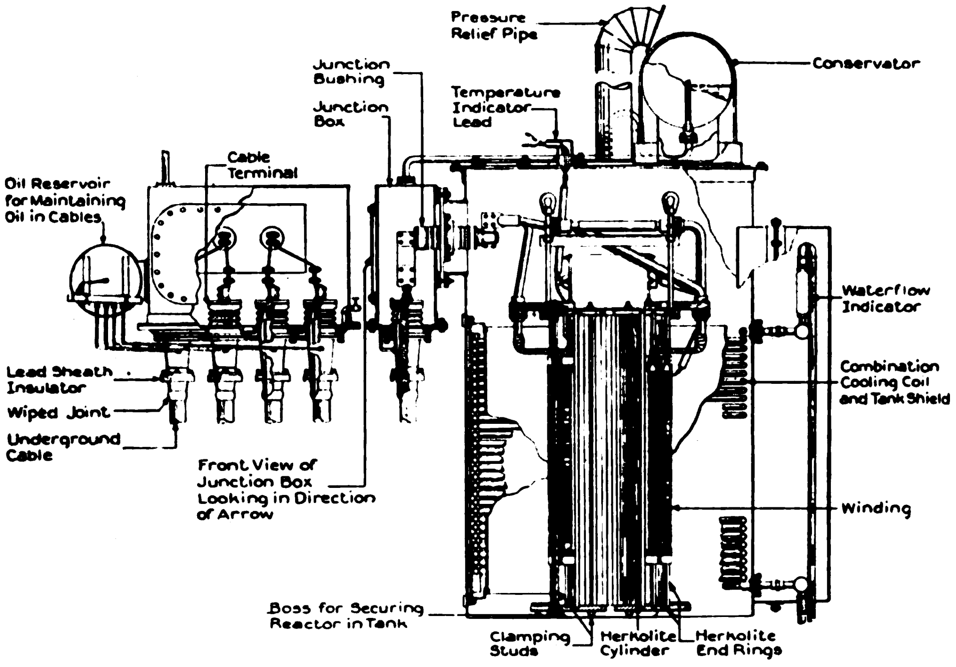
Pressure Relief Pipe
Conservator
Junction Bushing
Junction Box
Temperature Indicator Lead
Cable Terminal
Oil Reservoir for Maintaining Oil in Cables
Waterflow Indicator
Combination Cooling Coil and Tank Shield
Lead Sheath Insulator
Wiped Joint
Underground Cable
Front View of Junction Box Looking in Direction of Arrow
Winding
Boss for Securing Reactor in Tank
Clamping Studs
Herkolite Cylinder
Herkolite End Rings

Fig. 3. Sectional Outline of an Oil-immersed Current-limiting Reactor

The impulse voltages that are built up in service between the turns and coils of reactors are low, for the electrostatic capacity between the winding of a reactor and ground is small because of the great distances to ground. The absence of an iron core and the necessity for a space for the magnetic flux between the winding and the clamping structure and the tank make these great distances to ground practicable. Blume and Boyajian[1] showed that the impulse voltages between the turns and coils of a winding having a high capacity to ground are greater than the impulse voltages between the turns and coils of a winding having a low capacity to ground. In brief, oil-immersed reactors not only have high insulation strength but are subjected in service to comparatively low impulse voltages between turns and coils.

The coils are ventilated with the same type of liberally-spaced oil ducts that have so successfully ventilated the windings of circular-coil transformers. Reactors have inherently a safe heating margin, since they have no no-load losses, and their load loss varies as the square of the load current. The average 24-hour temperature of a reactor is therefore low. Fig. 1 shows the winding of a single-phase 60-cycle 2750-kv-a. reactor of this type used in a 22,000-volt circuit to introduce 9.2 per cent reactive drop in a 90,000-kv-a. three-phase circuit.

Fig. 2 shows the winding of a single-phase 60-cycle 2800-kv-a. reactor used to sectionalize a 120,000-volt bus of a large generating station. Six 75,000-kv-a. generators are connected to this bus through transformers. These reactors are probably the first to be built for 120,000-volt service; and on account of the high voltage and great kv-a. capacity are the largest so far constructed. The windings are wound on thick Herkolite cylinders which fit in grooves in the top and bottom clamping plates. The windings are spaced from the clamping plates by heavy Herkolite end rings that provide high insulation between the winding and the clamping structure and have great mechanical strength with which to transmit the clamping pressure to the winding. These parts are shown in Figs. 1, 2, and 3. The clamping plates are drawn securely against the end rings by five or more non-magnetic studs of material having an elastic limit of 60,000 to 70,000 lb. per sq. in. Four of these studs screw into the bottom of the tank and hold the winding rigidly in its place in the tank.

Tank Shield

If the magnetic flux of the reactor were allowed to flow into the wall of the tank it would generate very

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(1) "Abnormal Voltages," by L. P. Blume and A. Boyajian, *A.I.E.E. Transactions*, 1919.

high losses in the tank. Two general methods are available for shielding the tank from this flux, as follows:

(1). The tank may be lined with low-resistance non-magnetic rings concentric with the reactor winding. The current induced in these rings keeps the flux out of the tank.

(2). The tank may be lined with a shield of laminated high-resistance magnetic material which provides a path of low reluctance for the flux and diverts the flux from the tank.

The oil-immersed reactors described in this article make use of the first method for shielding the tank. Copper rings are forced tightly against the tank wall and welded in place, as shown in Fig. 4. The current flowing in the shield is limited to a definite value by the reactance of the shield, and the losses in it are held to the desired value by properly proportioning its cross section.

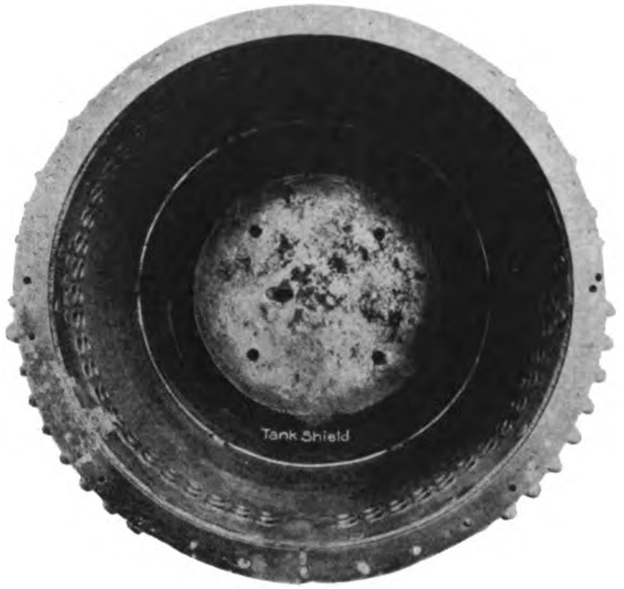


Fig. 4. Interior of Tank for a Self-cooled Oil-immersed Reactor, Showing the Copper Shield

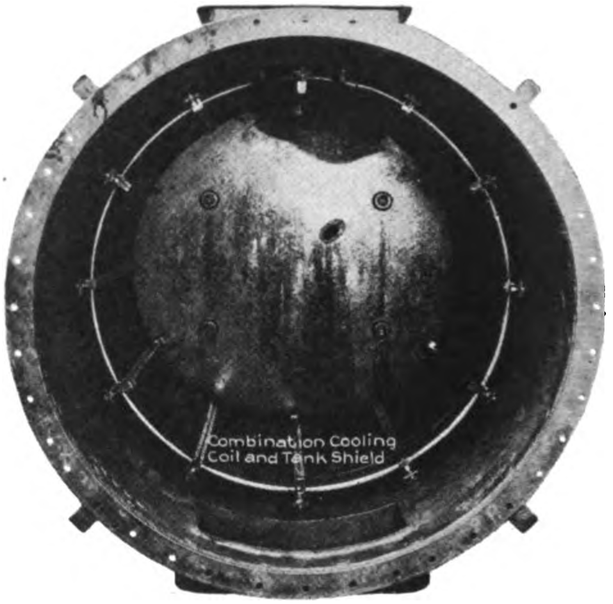


Fig. 5. Interior of a Tank for a Water-cooled Reactor, Showing the Combination Cooling Coil and Tank Shield

In a water-cooled reactor the copper cooling coil is so arranged that in addition to cooling the reactor it shields the tank in the same manner as do the rings in a self-cooled reactor. Such a combination cooling coil and shield is shown in Fig. 5.

The method of shielding the tank by means of copper rings has the following advantages:

(1). Owing to the small number of parts (usually not more than five heavy copper rings) the mechanical construction is exceptionally sturdy. Moreover, the magnetic forces press the shield more firmly in place against the tank, as is explained later. On the other hand, the magnetic type of shield consists of a multiplicity of long, narrow laminations and other small parts that are acted upon by magnetic forces which tend to pull the shield from the tank toward the reactor.

(2). The copper-shielded reactor has constant reactance at all currents while the reactor shielded by magnetic material has a serious reduction in reactance under short circuit due to the saturation of the shield. Therefore, a reactor with a magnetic shield should have greater reactance and kv-a. capacity at normal current than a reactor with a copper shield in order that it may have the same reactance at short circuit. This point is shown by the diagram in Fig. 6.

(3). The copper shield is equally effective at all currents, thus keeping excessive fluxes out of the tank wall at times of short circuit. Furthermore, the losses and resultant heating in this shield under short circuit are readily calculated and therefore under the exact control of the designer. The magnetic shield, however, becomes saturated during short circuit, permitting a large amount of flux to enter the tank wall which generates tremendous losses. These losses, which are difficult to calculate, are concentrated in a comparatively small portion of the tank and may cause sufficient heating to seriously damage the adjacent oil.

Summarizing: because of its sturdy construction and the fact that magnetic forces tend to hold the shield in place, its constant reactance at all loads, and its definite and lower heating, the copper shield is considered the better and safer means of shielding the tank.

Magnetic Forces

The magnetic forces which are now to be described as occurring in oil-immersed reactors may be divided with reference to their direction and location as follows:

(1). The force tending to decrease the axial length of the winding.

(2). The radial force tending to increase the diameter of the winding.
(3). The radial repulsive force between the reactor winding and the tank shield.
(4). The axial repulsive force between the winding and the shield.

(1). *Force Tending to Decrease Axial Length of Winding*

The magnetic field produced by the reactor winding exerts a force upon the turns of this winding which tends to compress the reactor to a shorter length and to bend the coils where they span the space between the radial spacers. These forces are of the same general nature and magnitude as in the "cast-in-concrete" reactor, the calculations of which have been well established. The support of the coils against these forces is readily accomplished by the use of a sufficient number of locked-in radial spacers so that the span of coil between these supporting spacers is not too great. Figs. 1 and 2 show the liberal use that is made of these spacers to obtain a strong support for the coils.

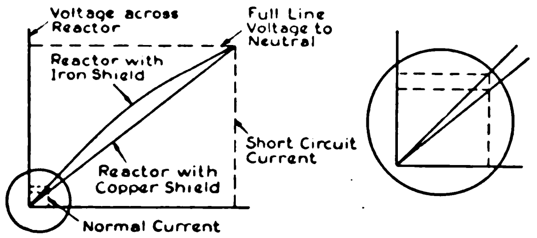


Fig. 6. Current-voltage Characteristics of Reactors Having Copper and Iron Shields. The circles emphasize the objectionably greater reactive drop of the reactor with the iron shield when carrying normal current

(2). *Radial Force Tending to Increase the Diameter of the Winding*

The magnetic field inside the winding and produced by the winding itself, exerts an outward radial force tending to increase the diameter of the winding. This force is resisted by the tensile strength of the conductor which would, of course, have to stretch in order for the diameter of the winding to increase. The strength of the conductor is many times greater than the force.

(3). *The Radial Repulsive Force Between the Winding and the Tank Shield*

This force is the repulsive force between two conductors (the winding and the shield) carrying currents in reverse directions, decreasing as the distance between the conductors increases. Since one of these conductors (the shield) surrounds the other (the winding) and both being circular in form it is obvious that if the distance between them at one point is small and the force great, then at a point diametrically opposite the distance will be great and the force small. As these are repulsive forces between the winding and the shield acting at two diametrically opposite points, the greater force overcomes the smaller; and if freedom of motion exists, the movement will be in such a direction as to increase the smaller distance and decrease the greater distance. From this reasoning it is seen that with free motion the winding would take a position concentric with the shield. In practice, the winding is assembled concentric with the shield and thus there is no resultant force tending to displace the winding. The effect of these radial forces on the winding is beneficial because they push it inward, tending to decrease its diameter and therefore slightly decrease the tension on the winding caused by the outward magnetic force due to the magnetic field inside of the winding. Their effect on the shield is also beneficial in that they tend to hold it securely against the tank wall where it belongs.

As pointed out before, this beneficial effect does not accrue to the magnetic type of shield because the force tends to tear such a shield loose from its fastenings to the tank and pull it toward the winding.

(4). *The Axial Repulsive Force Between the Winding and the Shield*

These forces depend for their amount and direction on the lengthwise alignment of the winding with the shield. If the mid-distance between the ends of the winding is on either side of the mid-distance between the ends of the shield the force will be in the direction increasing the separation between these mid-distances. On the other hand, if the mid-distances are exactly in alignment the force will be zero. It is not difficult to align the shield with the winding and in practice this alignment is accurately made, resulting in negligible axial forces between them.

In the copper-shielded oil-immersed reactor the winding is essentially the primary of a concentric-coil air-core transformer while the shield is the secondary. Although these two windings are very loosely coupled magnetically, the forces between them are of the same general nature as forces in a concentric-coil power transformer but with the very important exception that the forces for a given misalignment are very much smaller than in a transformer. The reason for this is that the forces are proportional to the product of the ampere-turns in both windings and, while the ampere-turns in both windings of a transformer are equal, the ampere-turns in the reactor shield are only from 11 to 14 per cent of those in the winding. Therefore the reactor forces are only 11 to 14 per cent as great as the force in transformers having the same misalignment.

The comparison between reactor and transformer forces has been made for the reason that the magnitude of transformer forces is well known to those familiar with the art. In a properly designed transformer these forces cause no concern; therefore, when the forces between the reactor and its shield are measured by transformer standards and found to be very much smaller, it is readily appreciated that they do not present a difficult problem in this type of reactor.

Tank and Bushings

The tanks in which these reactors are placed are of the same general construction as is used for transformers. Fig. 7 shows the tank for a 120,000-volt

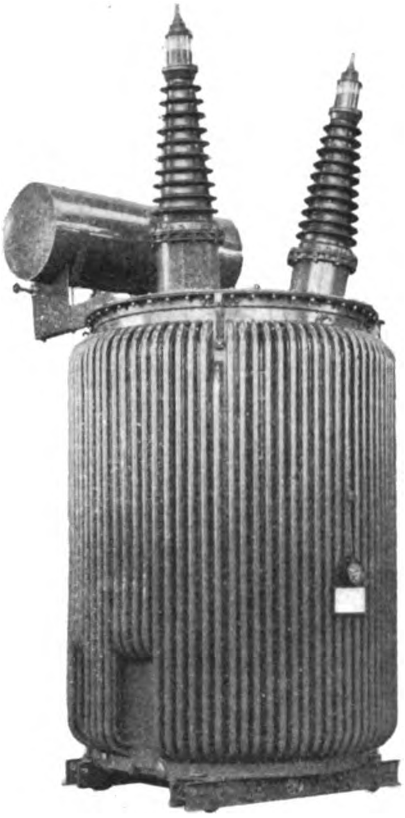


Fig. 7. Exterior of the Self-cooled Reactor Shown in Fig. 2

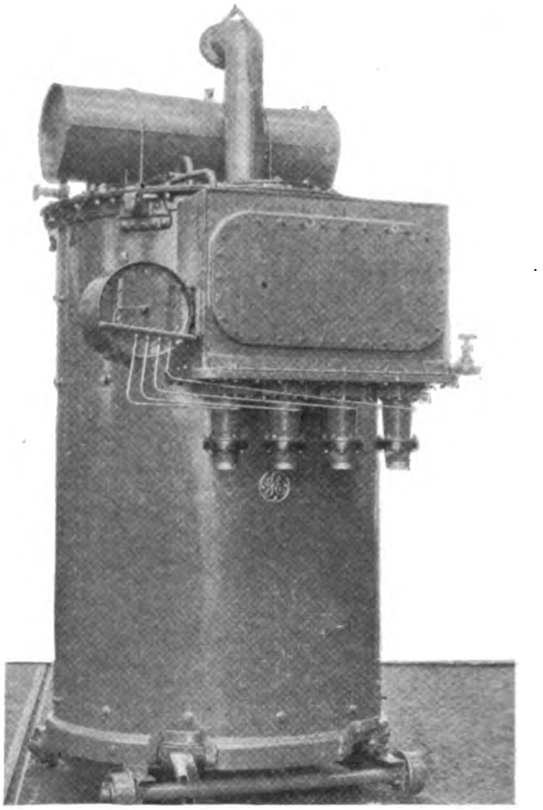


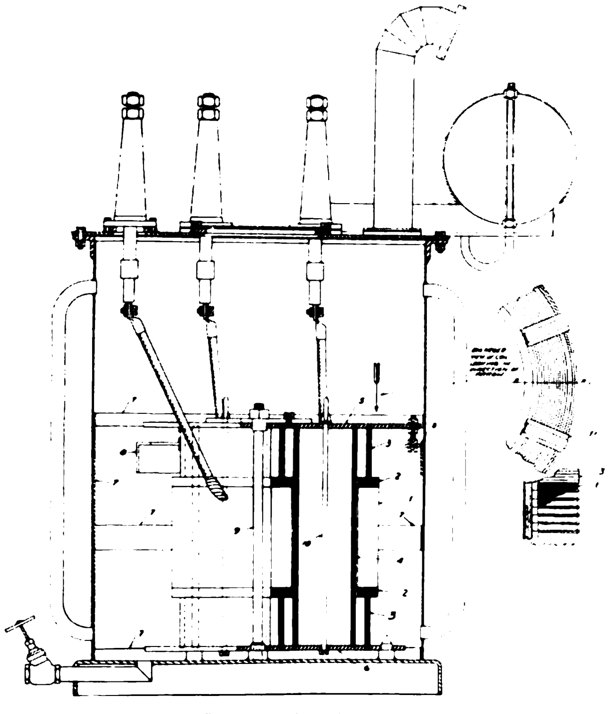
Fig. 8. Exterior of the Water-cooled Reactor Shown in Fig. 1. Note glands for making wiped joints to lead-covered cables. No live parts are exposed

LEGEND FOR FIG. 9 (a) AND FIG. 9 (b)

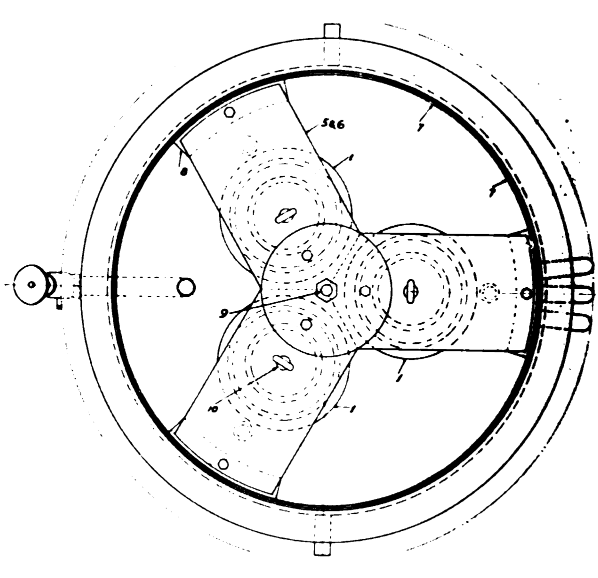
1. Winding
2. End Ring ⎫
3. Coil Support ⎬ Herkolite
4. Cylinder ⎭
5. Top Clamping Plate
6. Bottom Clamping Plate
7. Tank Shield
8. Clamping Angle

9 & 10. Clamping Studs

11. Radial Spacers



(a). Sectional elevation



(b). Interior plan view

Fig. 9. Oil-immersed Three-phase Current-limiting Reactor

2800-kv-a. self-cooled reactor, while Fig. 8 shows one for a water-cooled reactor.

Three-phase reactors are usually placed in a triangular arrangement in round tanks, as shown in Fig. 9, although, where a long, narrow space is available for their installation, they may be placed in a straight-line arrangement in oval tanks.

The terminals of the reactor may be brought out either through standard transformer bushings, as shown in Fig. 7, or they may be brought out into a junction box attached to the reactor tank where they are connected directly to underground cables as shown in Figs. 3 and 8. When thus connected the lead sheath of the cable is wiped to glands bolted to the junction box and all live parts are enclosed. Any possibility of the reactor's being grounded by birds, animals, dirt or other deposit on the insulator, or by falling objects, is thus eliminated. Troubles due to atmospheric disturbances are also eliminated.

Losses

The losses in these reactors are so low that the power-factor is nearly zero. This low power-factor makes the losses very difficult to measure and there has been developed an especially low-power-factor watt meter to measure them correctly. As a result of the development of these meters the losses which are guaranteed are true a-c. losses as required by A.I.E.E. specifications, and not simply I^2R losses.

Field of Application for Oil-immersed Reactors

In the following are indicated some of the applications for this type of reactor:

(*A*). For installations where, owing to the very large capacity and importance of the central station, it is desirable to be ultraconservative and shield the reactors from all exterior conditions that might affect their reliability. In stations of this character the reactors would be in circuits of 12,000 volts and higher

(*B*). In outdoor installations of reactors it is more difficult to control the exterior conditions and therefore there is greater incentive to use the oil-immersed type. Because of the importance of the apparatus they protect, large bus reactors for 12,000-volt circuits and above, installed outdoors, should preferably be oil-immersed. Feeder reactors for outdoor installations above 26,400 volts should be metal-enclosed.

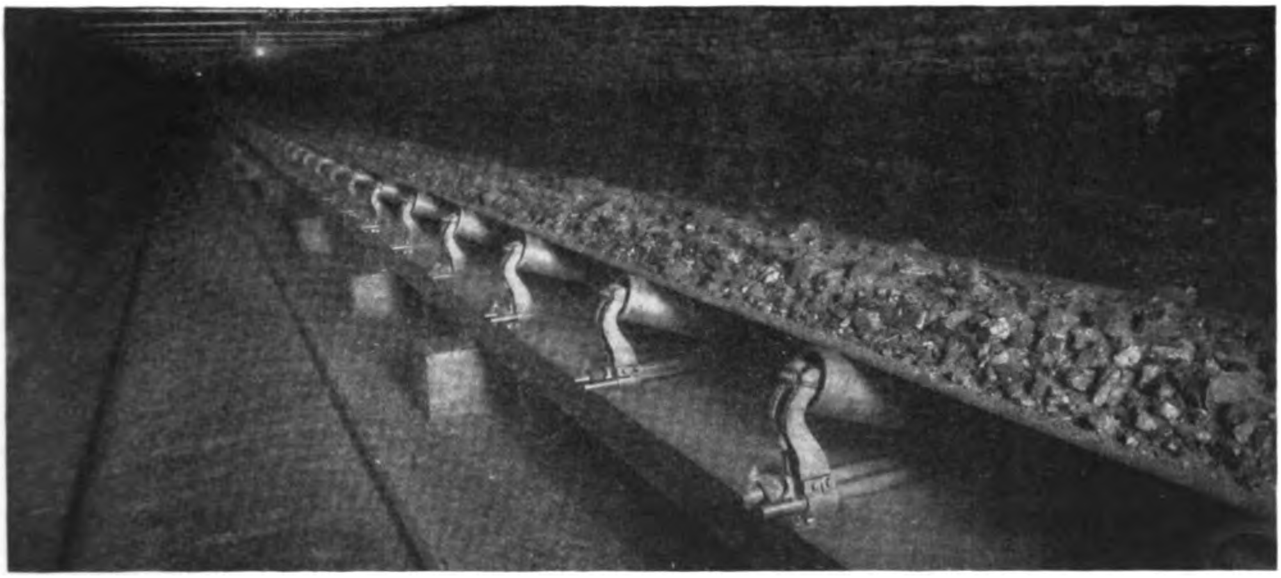
(*C*). Indoor reactors above 33,000 volts should be oil-immersed.

(*D*). Where it is difficult to provide cell construction oil-immersed reactors may be used to advantage.

(*E*). Where several banks of large transformers are connected together on the high-voltage side the high-voltage buses should be sectionalized. Oil-immersed reactors have already been supplied to sectionalize 120,000-volt buses.

(*F*). Water-cooled reactors may often prove economical, particularly if they are used for bus sectionalizing. In such service they normally carry very little current and therefore they can have relatively high losses, which are readily dissipated by the cooling water.

Miles of Coal



By means of this four-mile conveyor, driven by twenty electric motors with automatic control, ten thousand tons of coal are hurried along underground in a single day

Industrial Electric Heating

PART IX: THE RESISTOR FURNACE (Cont'd)

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THE primacy of the resistor furnace, in manufacturing, rests largely upon three distinctive features, *viz.:* (*a*) accuracy of control over the flow of energy; (*b*) uniformity of heat distribution; and (*c*) freedom in the use of definite atmospheres in the heating chamber. The first two features are of well-recognized value. The third is beginning to be appreciated, and as it comes into general use will materially expand the field of the resistor furnace. The topic here presented is this third element of the resistor furnace—the atmosphere of the heating chamber—and is a continuation of the introductory paragraphs on the subject in Part II of this serial.

The practical independence of heating chamber and source of heat in the resistor furnace is the freedom which makes possible a consideration of the atmosphere as an individual agent in the use of energy as heat and also permits the control of the function of that atmosphere with almost the same degree of precision that is characteristic of the control of electric energy. These features have long been desired by furnace operators.

The atmospheres in the heating chambers of resistor furnaces may be classified as: (*a*) natural atmospheres; (*b*) artificial atmospheres. The first, as the name suggests, is the result of entrained air, air leakage (by intent or otherwise) into the heating chamber, and gases liberated from the charge as the heating operation proceeds. The composition of a natural atmosphere varies during the heating period according to the degree that the heating chamber is sealed, the temperature of the heating chamber (which determines the extent of liberation of the gases from the charge), and the chemical reactions of the gases and solids in the chamber. The gases liberated from the charge vary in both kind and quantity, and depend largely upon the previous history of the metal of the charge. No two charges are alike in this respect. In some cases with high space-factors these gases may form a large part of a natural atmosphere; in other cases even with high space-factors the quantity of these gases may not be sufficient to be of consequence. Hence a natural atmosphere is individual for each charge, although charges that are uniform in kind and weight give fairly uniform atmospheric conditions when subjected to the same heat-treatment process. An example of a natural atmosphere made up largely from gases liberated from the charge is given in Part II, page 556. In this case the charge consisted of sheet steel with a high space-factor and the heating chamber was sealed.

A heating chamber is a receptacle immersed in air, which is a mixture of nitrogen and oxygen and various impurities. These impurities, such as water vapor from quenching tanks, oil vapor, fumes of various kinds from nearby industrial plants, etc., are sometimes the unsuspected source of trouble in furnace operation.

There is no control over gases liberated from a charge. The only control over a natural atmosphere is the control over the admission of air to the heating chamber, obtained by sealing the chamber and using throttled vents. A sketch of a seal with which sand, fine shot, water, or oil, can be used is shown in Fig. 139. The use of a liquid seal introduces the possibility of contamination of the heating chamber atmosphere by evaporation of the liquid. A natural atmosphere is effective mainly in the control of oxidation of the charge; and this has been found to be of much value in many cases where the use of an artificial atmosphere is not warranted.

A temporary atmospheric condition due to gases liberated from the walls sometimes occurs in the heating chambers of new furnaces. After the furnace has been in use for a period this action ceases. However, if the temperature of the heating chamber is raised to some value above that previously used, the liberation of gases from the walls may be renewed and continue for a time. This atmospheric condition, usually undesirable, can be remedied by ventilation of the heating chamber until the action is reduced to such an extent as to be unobjectionable.

An artificial atmosphere is an atmosphere that is maintained in a heating chamber by the introduction of a gas, or mixture of gases, of predetermined composition. This atmosphere is selected for some particular function with reference to the metallurgical

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The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Equations*	*Examples*	*Tables*	*Footnotes*
Part I	Oct. 1927, p. 488	1 to 23	(1) to (8b)	1 to 3	I to III	(1) and (2)
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Part II	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	———	X to XX	(16) to (26)
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chemical reactions that occur at elevated temperatures. In the selection of the artificial atmosphere, the gases that may be liberated from the charge must be taken into consideration and a continuous flow of the selected gas or gases through the heating chamber must be provided in order to maintain the desired character of the artificial atmosphere. The maintenance of a pressure below atmospheric pressure in the heating chamber, for example the vacuum furnace of Fig. 39, probably would also come within the classification of artificial-atmosphere applications.

The first effort towards an artificial atmosphere was the burning of a small amount of fuel—gas, oil, charcoal, etc.—in the heating chamber during the initial part of the heating period. This combustion consumed the oxygen of the air entrained with the charge and thus tended to protect the charge against oxidation. At best the method was only an approximation and the results obtained were variable.

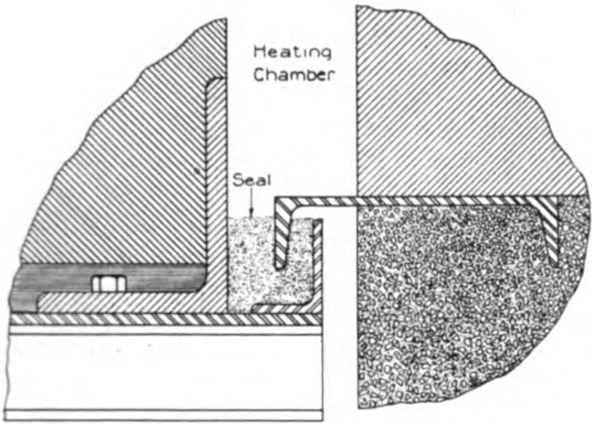

Fig. 139. Sketch of Gas Seal for Heating Chambers

The bath method of heating is, in principle, the use of an artificial atmosphere for the protection of the charge against oxidation or, as in cynaniding, for a change in the physical properties of the charge, such as surface hardening, through the action of the bath on the metal. Also the packing of charges in solid material, either for protection against oxidation or for an action such as carburizing, also may be included as an application of the principle of artificial atmospheres. However at this time we are concerned only with the use of gases for artificial atmospheres.

A classification defining the use of gas atmospheres on the dual basis of the material to be heated and the process in view is as follows:

(*a*). Processes in which the result, wholly or in part, is due to the formation of an oxide. One example is the baking of oil-bonded sand cores (see Fig. 33). This is an oxidation process. A second example is vitreous enamelling in which the bond between the ground coat and the base metal is formed by an oxide. For processes of this kind natural atmospheres are used.

(*b*.) Processes for which the oxygen content of a natural atmosphere is permissible provided it is restricted by a closed, but not necessarily sealed, heating chamber. An example is the annealing of steel parts preliminary to machining. A certain limited amount of scaling, *i.e.*, surface oxidation, is acceptable, the limitation being that the degree of this action must not make machining difficult.

(*c*). Processes for which the atmosphere of the heating chamber must be neutral, *i.e.*, without effect upon the material of the charge. The annealing of copper(48) in an atmosphere of steam is an illustration of processes of this kind.

(*d*). Processes which require an atmosphere which will bring about the reduction of an oxide. The use of hydrogen as a flux in the brazing of steel parts is an example.

(*e*). Processes which require holding the charge at an elevated temperature for a period of time. Here excessive oxidation would result if oxygen is permitted access to the charge, and the atmosphere of the heating chamber must be neutral or, as is generally used, reducing in character. An example is the heat treatment of steel to improve its magnetic properties.

(*f*). Processes in which a constituent of the heating chamber atmosphere combines with the charge to change some physical property of the material as in gas carburizing, nitriding, etc.

(*g*). Processes for the purification of metals. Such processes are at present mainly in the developmental stage.

The effects of the atmosphere in a heating chamber upon the material of a charge are due to chemical reactions and to obtain an artificial atmosphere that will produce beneficial results requires the observance of the laws relating to the influence of temperature and pressure on metallurgical and chemical reactions. The more important of these laws are those relating to reaction velocities, partial pressures of gases, dissociation of gases, chemical equilibriums, and the dissociation of metallic oxides. These laws and their relation to furnace practice will be reviewed briefly.

The velocity of a chemical reaction depends upon the nature of the substances involved, upon the concentration (mass per unit volume) of these substances—the greater the concentration the more frequent the collisions between the molecules—and upon temperature. A rise in temperature increases the velocity of the molecules and hence the number of their collisions per unit of time. Molecules must come together in order to combine, hence both increasing concentration and rising temperature accelerate chemical reactions. As all furnace operations are at elevated temperatures, comparatively high reaction velocities exist in all cases which we have to consider.

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(48) "The Annealing of Copper," by N. R. Stansel, GENERAL ELECTRIC REVIEW, May, 1927, p. 276.

Dalton's law states that in a mixture of gases the partial pressure (49) of each individual gas in the mixture is independent of the partial pressures of all other gases present in the mixture and the sum of the partial pressures of all of the constituent gases equals the total pressure. There are some deviations from this law, particularly at high pressure, and these deviations can be explained by assumptions involving the attractive forces between molecules, and the volume and the shape of the molecules. However, for the conditions which we are to consider we can accept Dalton's law without modification.

At elevated temperatures the gases which are used for artificial atmospheres are dissociated; but the dissociation in the case of any one gas is not complete, as equilibrium is established when the mixture formed by the gas and the gas products of dissociation has reached a definite composition. As a general rule applying to the dissociation of the gases which we will consider, the higher the temperature the greater is the degree of dissociation. Assume for a given gas in a closed chamber in which a constant pressure can be maintained that the dissociation process has reached equilibrium at a given temperature (t). Now if the temperature is lowered to some value (t_1) a new equilibrium is established by the combining of the gas products of dissociation; the lower the new temperature (t_1) the more complete being the combination. Thus for such reversible reactions there is a condition of equilibrium for each temperature, which is the common limit of two reactions each the inverse of the other; and this equilibrium is the limit to which we can go in the utilization of such reactions for a given end. In practice the conditions are made such that the desired result is attained before the system reaches equilibrium.

Reactions of this kind illustrate the general law of chemical equilibrium for gases (or the law of mass action) which is stated thus: (50) "The product of the partial pressures of the substances formed in a chemical reaction, each raised to a power which is the coefficient of its formula in the chemical equation, divided by the product of the partial pressures of the reacting substances, each raised to a power which is the coefficient of its formula in the chemical equation, is constant when equilibrium is attained." The quotient thus obtained is termed the dissociation constant of the reacting substances. This constant varies with temperature.

To illustrate this law we may take the dissociation of water vapor—a gas invariably present to some extent in the atmospheres of heating chambers and a gas that is an important factor in the use of artificial atmospheres. We have the chemical equation

$$2\,H_2O \rightleftarrows 2\,H_2 + O_2 \qquad (26)$$

and at equilibrium

$$K_t = \frac{(p_{H_2})^2 \times p_{O_2}}{(p_{H_2O})^2} \qquad (27)$$

in which

K_t = the dissociation constant of water vapor at temperature (t)
p_{H_2} = the partial pressure of hydrogen at temperature (t)
p_{O_2} = the partial pressure of oxygen at temperature (t)
p_{H_2O} = the partial pressure of water vapor at temperature (t).

Let us assume a vessel containing water vapor brought to a temperature t. At that temperature the water vapor is dissociated to a certain degree and the system, water vapor—oxygen—hydrogen, is in equilibrium. Prior to the attainment of equilibrium, the partial pressure of water vapor is higher than that corresponding to equilibrium and the water vapor continues to dissociate faster than the elementary gases, the hydrogen and oxygen produced by dissociation, can combine. If after equilibrium is attained the temperature is lowered, a corresponding new equilibrium is established by the combination of hydrogen and oxygen to form water vapor.

The per cent dissociation of water vapor at different temperatures, from data by Langmuir, (51) is given in Table XXIX.

TABLE XXIX

TEMPERATURE			Water Vapor Per Cent Dissociation
Deg. F.	Deg. C.	Deg. K.	
1340	727	1000	0.000028
1700	927	1200	0.000745
1880	1027	1300	0.00266
2060	1127	1400	0.00787
2240	1227	1500	0.0197
2420	1327	1600	0.0446
....	....	1700	(x) 0.0920
....	....	1800	0.170
....	....	1900	0.302
....	....	2000	0.504
....	....	2200	1.21
....	....	2500	3.38
....	....	3000	11.10

(x) Values above this line are within the temperature range of the resistor furnace.

Metallic oxides present an important problem in the technique of heat treatment processes as may be noted in a preceding paragraph in the classification of processes with reference to heating chamber atmospheres. In some cases the object is the formation of an oxide; but the more common phase of the problem is the prevention of oxidation and the reduction of oxide already formed on the surfaces of the metal of a charge.

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(49) Partial pressure: that part of the total pressure due to a particular gas in a mixture of gases.

(50) See Millard: *Physical Chemistry for Colleges*, McGraw-Hill Book Co., Inc., 1921.

(51) "The Dissociation of Water Vapor and Carbon Dioxide at High Temperatures." *Jour. Amer. Chem. Soc.*, Vol. 28, p. 1357.

Metallic oxides are dissociated by heat, the conditions for dissociation being individual in each case. In such chemical reactions we find an analogy to the changes in physical state represented by the vaporization of liquids. Saturated vapor pressures (52) of liquids have fixed and individual values corresponding to definite temperatures, the higher the temperature the higher the saturated vapor pressure. For example, the pressure-temperature relation of saturated water vapor is shown in Fig. 140. Other substances exhibit similar characteristics. A saturated vapor pressure is the same whether the vapor is alone or mixed with other gases, and the same whether in a closed chamber or in the open air. The analogy is found in that metallic oxides under equilibrium conditions exert partial pressures of oxygen which, like saturated vapor pressures, are dependent upon temperature but independent of other gases which may be present in the atmosphere surrounding the oxide.

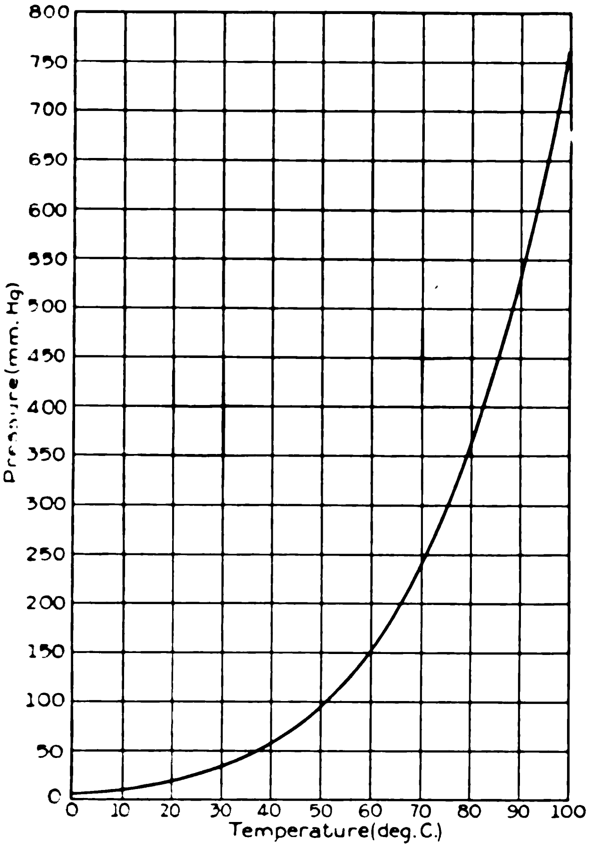

Fig. 140. Pressure-temperature Relation of Saturated Water Vapor

The dissociation of metallic oxides by heat is illustrated by the dissociation of mercuric oxide (53) into metallic mercury and oxygen. Heat mercuric oxide to a temperature *t* in a closed chamber from which the air has been exhausted and to which is connected a pump. The pump serves either to remove the oxygen produced by dissociation of the oxide or to force oxygen into the vessel. If the temperature (*t*) is, say, 600 deg. C. (1112 deg. F.) the dissociation of the oxide ceases when an oxygen pressure of 1.6 atmospheres is reached. At that temperature and pressure the system, mercuric oxide—metallic mercury—oxygen, is in equilibrium. If the oxygen pressure is now lowered, the dissociation of the oxide is resumed. If the oxygen pressure is raised above 1.6 atmospheres —the temperature remaining constant at 600 deg. C.—the reaction is reversed, *i.e.*, we have oxidation of the metallic mercury. This reaction expressed in symbols is

$$2\,HgO \rightleftarrows 2\,Hg + O_2 \qquad (28)$$

At equilibrium the oxygen pressure is termed the dissociation pressure of the oxide at the stated temperature. Thus the dissociation pressure of mercuric oxide at 600 deg. C. is 1.6 atmospheres (23.5 lb. per sq. in.).

In this experiment we note that with only oxygen as the atmosphere of the chamber we can have at will a reduction of the oxide, a neutral condition, or an oxidation of the metal. This leads to the general statement that the terms oxidizing atmosphere, neutral atmosphere, and reducing atmosphere as applied to furnace practice are incomplete unless there are stated the conditions relating to the atmosphere, the temperature, the pressure, the chemical composition of the gas or gases forming the atmosphere, and the nature of the charge with which the atmosphere is associated. We will have occasion to refer again to this phase of the subject.

In the experiment illustrating the dissociation of metallic oxides by heat we could start with the chamber containing an inert gas, *e.g.*, nitrogen. This does not change the result in any way except that we measure the total pressure in the chamber, which is the sum of the partial pressures of nitrogen and oxygen; and in order to obtain the partial pressure of oxygen we must subtract the partial pressure of nitrogen from the gauge reading.

All other metallic oxides have definite dissociation pressures at definite temperatures; and for each oxide the dissociation pressure increases with rise of temperature. The theoretical dissociation pressures of metallic oxides can be calculated by an equation developed by Nernst whereby Stahl (54) constructed Table XXX. It has been found that Stahl's values are only approximate, but the table is of importance in showing that the dissociation pressures of the oxides of the common metals are very low at

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(52) Saturated vapor pressure: the vapor pressure corresponding to a definite temperature at which a substance and its vapor remain in equilibrium.

(53) This reduction of mercuric oxide to mercury may go through an intermediate stage of oxidation such as mercurous oxide, Hg_2O.

(54) *Metallurgie*, Vol. 4, p. 682. The Nernst equation is:

$$\log p = -\frac{Q}{4.57\,T} + 1.75 \log T + 2.8$$

in which

p = partial pressure of oxygen in equilibrium with a metallic oxide
Q = heat of reaction per gram molecule of the oxide at ordinary temperature
T = absolute temperature, deg. C.

usable temperatures. On the other hand, the dissociation pressures of the oxides of the noble metals even at moderate temperatures are high. For an example, see Fig. 141, which shows the relation between dissociation pressure and temperature for silver oxide as given by data compiled by Lewis and Randall.(55) Note the similarity of this curve to the curve of Fig. 140, the pressure-temperature relation of saturated water vapor.

When a metal has two oxides, the mixed oxides exhibit a definite dissociation pressure for each temperature just as in case of the simple oxides. The only difference is that if the partial oxygen pressure is raised above the dissociation pressure both the metal and the lower oxide will be oxidized, while if the partial oxygen pressure be lowered below the dissociation pressure then both the higher oxide and the lower oxide will be reduced. An example of mixed oxides is given by Smyth and Roberts(56) for the system

$$4\ CuO\ (solid) \rightleftarrows 2\ Cu_2O\ (solid) + O_2\ (gas) \qquad (29a)$$

$$4CuO\,(solid) \rightleftarrows 2Cu_2O.\ xCuO\,(liquid) + O_2\,(gas) \qquad (29b)$$

for which the dissociation pressure—temperature relation—is shown in Fig. 142.

It has been seen that the liberation of oxygen from a metallic oxide is a thermodynamic reaction, the requirement for this reduction being that the partial oxygen pressure over the surface of the oxide be maintained below the dissociation pressure of the oxide at the particular temperature chosen. From Table XXX it is noted that the reduction of the oxides of the common metals in this way requires lower oxygen pressures (higher vacua) than are practicable to obtain by exhaustion. It has been proposed to obtain such low pressures by passing an inert gas over the hot oxide surface, thus sweeping away the oxygen as fast as it is liberated from the oxide. This method fails however since, owing to the viscosity of the inert gas, a stationary film of the gas forms over the surface of the oxide; and this blanket effect defeats the effort to remove the oxygen in that way.

The feasible method of obtaining the low partial oxygen pressures necessary for the reduction of the oxides of many of the common metals by heat is to heat the oxide in an atmosphere of an easily oxidizable gas, such as hydrogen or carbon monoxide. Such gases at elevated temperatures unite rapidly

TABLE XXX

DISSOCIATION PRESSURE IN ATMOSPHERES

Temp. Deg. C.	Temp. Deg. K.	$2\ Cu_2O \rightleftarrows 4\ Cu + O_2$	$2\ PbO \rightleftarrows 2\ Pb + O_2$	$2\ NiO \rightleftarrows 2\ Ni + O_2$	$2\ ZnO \rightleftarrows 2\ Zn + O_2$	$2\ FeO \rightleftarrows 2\ Fe + O_2$
227	500	6.5×10^{-30}	3.1×10^{-38}	1.8×10^{-46}	1.3×10^{-68}	
327	600	8.0×10^{-24}	9.4×10^{-31}	1.3×10^{-37}	4.6×10^{-56}	5.1×10^{-42}
427	700	1.9×10^{-19}	2.1×10^{-26}	2.8×10^{-31}	4.3×10^{-47}	
527	800	3.6×10^{-16}	2.3×10^{-21}	1.7×10^{-26}	2.4×10^{-40}	9.1×10^{-30}
627	900	1.7×10^{-12}	3.2×10^{-18}	8.7×10^{-23}	4.3×10^{-35}	
727	1000	1.5×10^{-11}	1.1×10^{-15}	8.4×10^{-20}	7.1×10^{-31}	2.0×10^{-22}
827	1100	7.8×10^{-10}	1.3×10^{-13}	2.3×10^{-17}	2.0×10^{-27}	
927	1200	2.0×10^{-8}	7.0×10^{-12}	2.6×10^{-15}	1.5×10^{-24}	1.6×10^{-19}
1027	1300	3.3×10^{-7}	2.1×10^{-10}	1.4×10^{-13}	4.3×10^{-22}	
1127	1400	3.6×10^{-6}	3.8×10^{-9}	4.4×10^{-12}	5.4×10^{-20}	5.9×10^{-14}
1227	1500	2.8×10^{-5}	4.8×10^{-8}	8.7×10^{-11}	3.6×10^{-18}	
1327	1600	1.8×10^{-4}	4.4×10^{-7}	1.2×10^{-9}	1.4×10^{-16}	2.8×10^{-11}
1427	1700	8.9×10^{-4}	3.2×10^{-6}	1.2×10^{-8}	3.7×10^{-15}	
1527	1800	3.8×10^{-3}	1.8×10^{-5}	9.6×10^{-8}	6.8×10^{-14}	3.3×10^{-9}
1627	1900	1.4×10^{-1}	8.9×10^{-5}	6.1×10^{-7}	9.1×10^{-13}	
1727	2000	4.4×10^{-1}	3.7×10^{-4}	3.3×10^{-6}	9.5×10^{-12}	1.6×10^{-7}

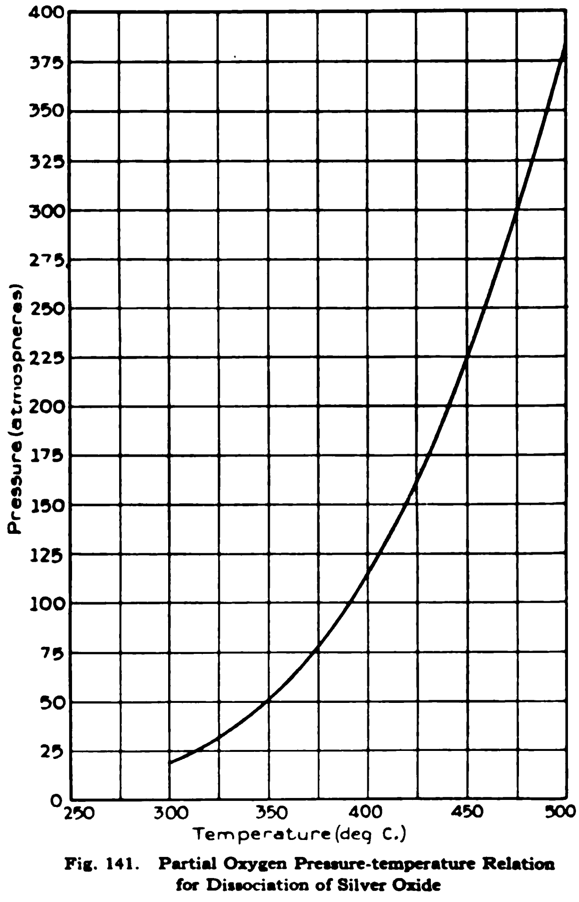

Fig. 141. Partial Oxygen Pressure-temperature Relation for Dissociation of Silver Oxide

with the oxygen liberated from the oxide and thus maintain a low partial pressure of oxygen (below the dissociation pressure of the oxide) over the hot oxide surface and there is obtained a continuous reduction of the oxide. This method, it will be noted, is the same as that of the example of the reduction of mercuric oxide given previously, the only difference being the procedure to maintain the partial pressure of oxygen below the dissociation pressure of the oxide. This action of these gases gives rise to the term reducing gas, generally applied to hydrogen, carbon monoxide, and some others, and we have correspondingly the term reducing atmosphere as used in furnace practice. We will see later, however, that there are qualifications in the use of this term for a particular gas.

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(55) Lewis and Randall: *Thermodynamics and the Free Energy of Chemical Substances*, McGraw-Hill Book Co., Inc., 1923, p. 480.

(56) "The System Cupric Oxide, Cuprous Oxide, Oxygen," *Jour. Amer. Chem. Soc.*, Vol. 42, p. 2582.

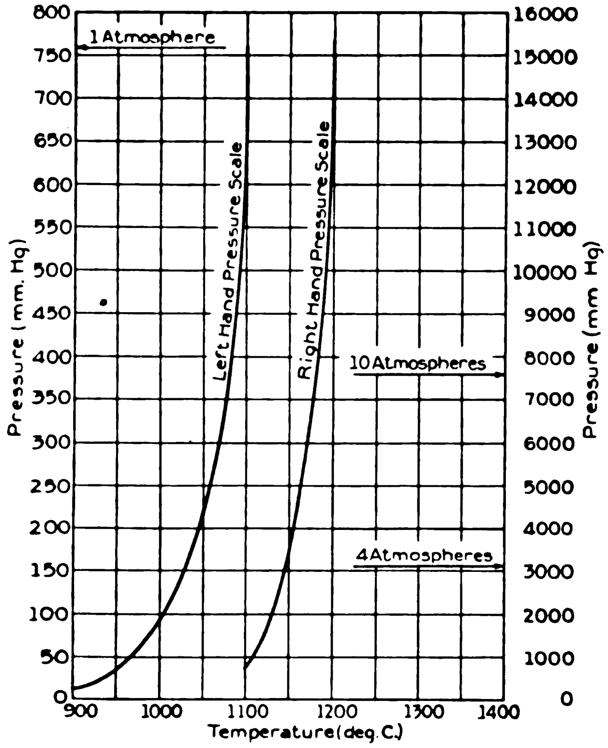

Fig. 142. Partial Oxygen Pressure-temperature Relation for Dissociation of Copper Oxide

In cases of some of the metallic oxides, *e.g.*, chromic oxide, aluminum oxide, etc., the dissociation pressures are so low that the above-noted method fails, and such oxides cannot be reduced by heating in an atmosphere of the so-called reducing gases.

As the dissociation pressures of metallic oxides increase with rising temperature and, likewise, reaction velocities also, the degree of the effectiveness of the reduction of the oxides of the common metals—for which the dissociation pressures are so low—by the reducing gas method is greater as the heating chamber temperature becomes higher. In this connection an investigation of Fay, Seekey, Lane and Ferguson(57) to determine the lowest temperature at which various metallic oxides begin to lose oxygen when heated in different gases is of interest. Some of the data of this investigation are given in Table XXXI.

Metallic oxides formed on the surfaces of metals by the action of heat, if of appreciable thickness, are termed scale. Slight oxidation or discoloration due to oxide films hardly come within the term scale; but the chemical reactions are the same regardless of the degree of the oxidation.

TABLE XXXI

Oxide	ATMOSPHERE—TEMPERATURE, DEG. C.			
	H_2	CO	NH_3	CH_4
Ag_2O	0	0	...	...
Hg_2O	0	0	67	220
HgO (red)	90	115	157	200–210
PbO_2	110	150	198	45
PbO	160	190	299	210
CuO	75	125	225	280
Cu_2O	...	...	208	230
ZnO	170	...	233	152–159

A common example of scaling is that which occurs when steel is heated in air. The product is ferro-ferric oxide of iron, thus:

$$3\,Fe + 2\,O_2 = Fe_3O_4 \qquad (30)$$

The combination is progressive, as indicated by the equations

$$2\,Fe + O_2 = 2\,FeO \qquad (30a)$$

$$6\,FeO + O_2 = 2\,Fe_3O_4 \qquad (30b)$$

The relation between the rate of scaling of heated steels in air and temperature was investigated by Dickenson(58) and the chart in Fig. 143 was plotted from data from that investigation. The analyses of the two steels included in Fig. 143 are given in Table XXXII.

From the curves in Fig. 143 it is noted that appreciable scaling does not begin until the steel reaches a temperature around 600 deg. C. (1112 deg. F.) and

TABLE XXXII
ANALYSIS

Metal	C	Si	Mn	S	P	Ni	Cr	W
Carbon Steel	0.30	0.12	0.54	0.027	0.038	0.51	0.14	......
High-speed Steel	0.65	0.30	0.22	0.041	0.027	0.12	3.73	13.86

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(57) "Initial Temperature at which Oxides of Metals Give Up Oxygen to Reducing Gases," *Poly. Engr.* Vol. 10, p. 72.
(58) "Note on the Scaling of Steels at Elevated Temperatures," *Engineering* (London), Vol. 114, p. 378.

that thereafter the rate of oxidation increases rapidly with temperature. The rate of scaling of steel heated in air depends upon the three factors: the solubility of the ferrous oxide (FeO) in the iron; the rate of penetration of oxygen through the oxide already formed; and the rate of the progressive reactions towards the final product. All of these are accelerated by rise of temperature. The general relation between rate of scaling of metals and temperature is expressed thus

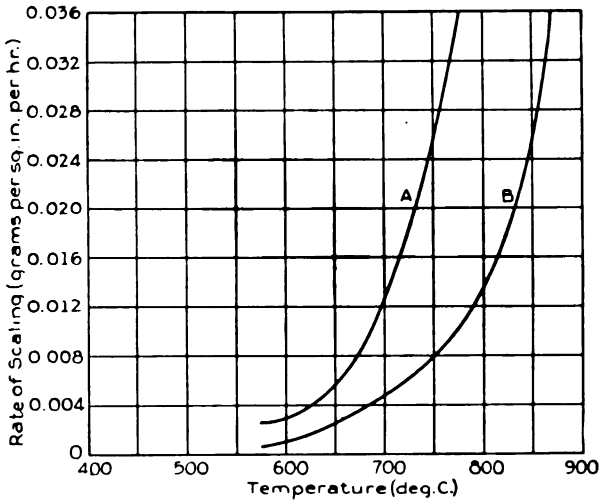

Fig. 143. Rate of Scaling of Steel at Elevated Temperatures in Air
(*A*). 0.30 carbon steel
(*B*). High-speed steel

$$R = cT^n \qquad (31)$$

in which

R = rate of scaling

T = absolute temperature

c and n are constants depending upon the particular metal.

Hydrogen is one of the most used gases for artificial atmospheres; the largest uses in this way being for the reduction of metallic oxides by heat and for the prevention of oxidation while metal is at an elevated temperature.

Commercial hydrogen contains more or less moisture, which, together with the water vapor formed in the oxide reduction, is subject to dissociation at furnace temperatures as noted in Table XXIX. At equilibrium in a system, metallic oxide—metal—hydrogen—oxygen—water vapor, we can write Equation (27) thus:

$$\frac{K_t}{p_{O_2}} = \frac{(p_{H_2})^2}{(p_{H_2O})^2} \qquad (32)$$

We have at equilibrium

p_{O_2} = the partial pressure of oxygen = the dissociation pressure of the oxide.

and thus we can write

$$\left[\frac{K_t}{p_{O_2}}\right]^{\frac{1}{2}} = \eta_t = \frac{p_{H_2}}{p_{H_2O}} \qquad (33)$$

in which

η_t = the equilibrium constant which is characteristic of the given oxide at temperature t.

The equilibrium constant η_t varies with temperature in accordance with the variations due to changes of temperature in the value of the dissociation constant K_t and with the variations in the value of the dissociation pressure of the oxide due to temperature changes.

As Equation (33) represents the equilibrium condition at temperature t in a system, metallic oxide—metal—hydrogen—oxygen—water vapor, at which the partial pressure of free oxygen (in equilibrium with hydrogen and water vapor in the gas phase of the system) is equal to the dissociation pressure of the oxide, it follows that at any temperature there is a definite mixture of hydrogen and water vapor which in contact with a metal and its oxide will not in effect bring about either oxidation of the metal or reduction of the oxide. Under this condition we therefore say that the atmosphere is neutral. Correspondingly, at any temperature (t) a variation from the ratio of hydrogen to water vapor (in the mixture of these two gases) which represents the neutral condition will bring about either oxidation of the metal (oxidizing atmosphere) or reduction of the oxide (reducing atmosphere) depending upon

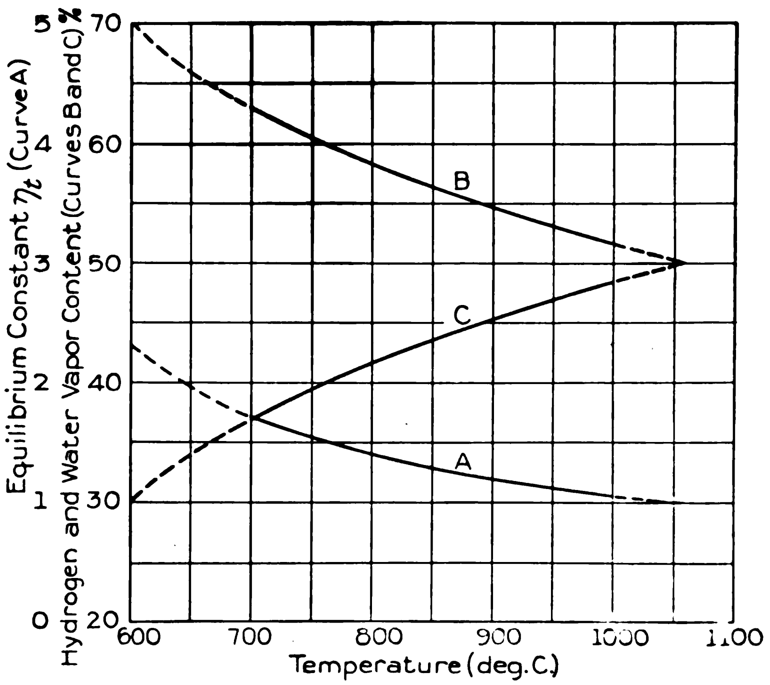

Fig. 144. Relation of the Equilibrium Constant and Temperature (Curve *A*); and Corresponding Percentages of Hydrogen (Curve *B*), and of Water Vapor (Curve *C*) in the Mixture of Hydrogen-water-vapor in Case of Reduction of Iron Oxide by Heat in a Hydrogen Atmosphere. The percentage of oxygen in the gas mixture is too small to show graphically

the proportions of the two gases in the hydrogen-water-vapor mixture.

The chart in Fig. 144, from data by Eastman and Evans,(59) shows the relation between the equilibrium constant (η_t) and temperature (Curve *A*) in the case of the reduction of iron oxide by heat through the use of hydrogen. The progressive reduction is indicated thus:

$$Fe_3O_4 + H_2 \rightleftarrows 3\,FeO + H_2O \qquad (34a)$$

$$FeO + H_2 \rightleftarrows Fe + H_2O \qquad (34b)$$

The chart shows also the corresponding relation between per cent hydrogen component in the hydrogen-water-vapor mixture and temperature (Curve *B*) and the corresponding relation between the water-vapor component in the hydrogen-water-vapor mixture and temperature (Curve *C*). For example, at a given temperature (t), say 885 deg. C., we can have any of the atmospheric characteristics shown in Table XXXIII by varying the ratio of the hydrogen to the water vapor in the hydrogen-water-vapor mixture.

TABLE XXXIII

Curve B Per Cent H_2	Curve C Per Cent H_2O	Character of Atmosphere At 885 deg. C.
50	50	Oxidizing
55	45	Neutral
60	40	Reducing

Thus if at the temperature of 885 deg. C. we increase the hydrogen content of the hydrogen-water-vapor mixture to some value above 55 per cent, the free hydrogen in the system combines with the free oxygen and thus lowers the partial pressure of oxygen below the dissociation pressure of the iron oxide and we have reduction of the oxide; *i.e.*, whatever the temperature may be, the percentage of hydrogen in the hydrogen-water-vapor mixture must be greater than the value for the given temperature as shown by Curve *B*, Fig. 144, to obtain reduction of iron oxide. (This is the same as stating that the percentage of water vapor in the hydrogen-water-vapor mixture at the given temperature must be less than the value shown by Curve *C* for that temperature to obtain reduction of iron oxide). The higher the hydrogen content of the hydrogen-water-vapor mixture, *i.e.*, the drier this mixture, the more effective is the reducing process.

It will be further noted from Fig. 144 that the higher the temperature the higher is the water-vapor content of the hydrogen-water-vapor mixture of the heating chamber atmosphere at equilibrium. Thus, in the reduction of iron oxide the higher the temperature the higher will be the permissible water-vapor content of the hydrogen-water-vapor mixture. As a general rule, however, we must safeguard the steel against oxidation during cooling to a point below the temperature at which oxidation becomes active (see Fig. 143). Then the upper operating limit of the water-vapor content of the hydrogen-water-vapor mixture is a value below the value shown by Curve C for 600 deg. C.; *i.e.*, some value lower than 30 per cent by a safe margin, say about 20 per cent or less.

(To be continued)

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(59) "Equilibria Involving the Oxides of Iron," *Jour. Amer. Chem. Soc.*, Vol. 46, p. 888.

California Irrigates Farms Electrically

According to the report of the California Railroad Commission the agricultural power sales in California for the year 1927 amounted to 719,830,660 kw-hr. Most of this power was sold to farmers for individual irrigation of farm lands by means of shallow wells operated by electric motors. It was sold at an average cost of 1¾ cents a kilowatt-hour. As it takes 150 kw-hr. to raise three acre-feet of water 35 ft., this means that for $2.50 a year the California farmer can irrigate an acre of his land.

The agricultural power sales in California are sufficient to place three feet of water on more than 5,000,000 acres, a tract of land 200 miles long and 40 miles wide. All of this water is pumped from shallow wells on the farms, with no expensive dams, flumes, irrigation ditches, heavy burdens of construction costs, silt deposits, or the alkaline deposits which come from erosion.

Much of the same sort of development has been going on in Texas. Not so long ago that vast territory lying west of the Brazos River and known as West Texas was considered only a barren waste. Today, it is said "the plows of a million prosperous and prospering farmers have given the laugh to the prophets and prognosticators of yesterday. West Texas today is one of the world's richest agricultural regions." This has been accomplished with shallow wells and the pumping of water from streams. The change has been made possible because of the extension of power lines and agricultural power.

Low-voltage A-c. Networks

PART IX: PROTECTIVE EQUIPMENT

By D. K. BLAKE
Central Station Engineering Dept., General Electric Company

THE utilization of the low-voltage a-c. network in modern distribution systems required the development of both high-voltage and low-voltage protective equipment for subway installation. Present network systems may be divided into two groups: those having high-voltage oil circuit breakers with low-voltage fuses, and those having low-voltage air circuit breakers with no high-voltage protective equipment. The latter is by far the more extensively employed, there being only two or three of the former type of systems.

Subway-type oil circuit breakers have been developed for 15,000-volt circuits and provided with six current transformers and six trip coils for use with the pilot-wire scheme previously described (Part VI). Provision is made for the use of single-conductor lead-covered cable for both the main power leads and pilot-wire leads to the current transformer. The breakers are manually operated but designed so that either a motor or solenoid mechanism may be added.

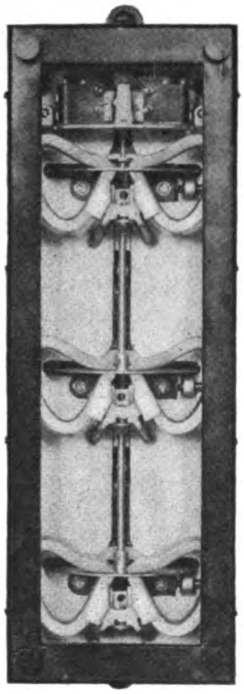

Fig. 58. Front View of a Three-phase Network Relay Showing Three Disks on Common Shaft with Single Contact Assembly

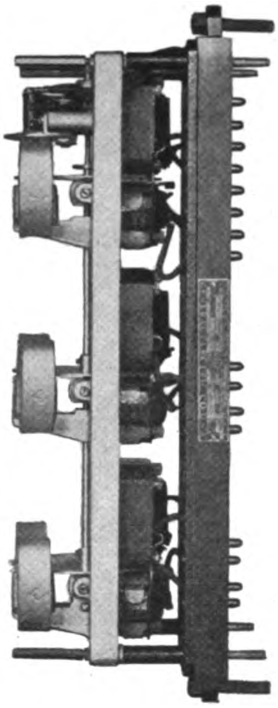

Fig. 59. Side View of Three-phase Network Relay with Cover Removed, Showing Simplicity of Construction and Plug Type Terminals

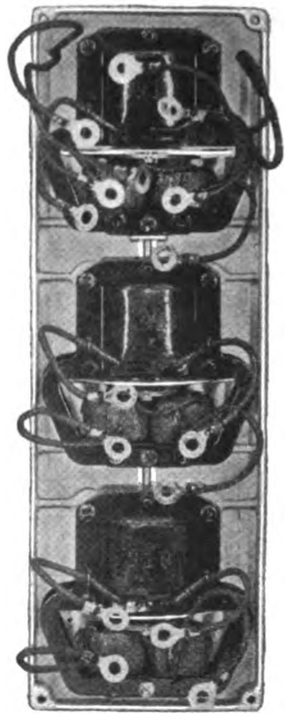

Fig. 60. The Three Power Elements of Three-phase Network Relay (back view) Showing Coil Connections with Elements Mounted on Supporting Grid

The low-voltage protective device consists of an electrically-operated air circuit breaker with a reverse-power and reclosing relay equipment. This combination is usually referred to as the "network protector." The development of this device incorporates several interesting features.

The relay equipment was required to trip on a range of reversals from transformer exciting current to short-circuit current and to reclose on a voltage difference of one-half to two volts. Both tripping and reclosing functions were incorporated in a single device constructed of watthour-meter parts with special coils and current transformers. Thus the mechanical parts of the relay are not new to the industry but are well understood by those acquainted with watthour-meter principles and construction. Even the adjustment of voltage reclosing values was accomplished by the well-known starting plate of watthour meters. The relay sensitivity was obtained electrically in the current transformer and ballistic

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The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Tables*	*Footnotes*
Part I	Feb., 1928, p. 82	1 to 4	——	(1)
Part II	Mar., 1928, p. 140	5 to 16	——	——
Part III	Apr., 1928, p. 186	17 to 19	I to VII	(2)
Part IV	May, 1928, p. 245	20 to 26	VIII	(3)
Part V	Aug., 1928, p. 440	27	IX to XII	(4) and (5)
Part VI	Sept., 1928, p. 480	28 to 33	——	——
Part VII	Nov., 1928 p. 600	34 to 45	——	——
Part VIII	Dec., 1928 p. 673	46 to 57	——	——

resistor design rather than mechanically in the relay itself. To facilitate testing and adjustment, the relays are provided with plug-type terminals that fit into spring-jack receptacles on the relay panel. Jack screws are used to force the plugs in or out of the receptacles and to hold the relay securely to the panel. Dowel pins are provided to insure the alignment of the plugs with the receptacles and to support the weight of the relay while the jack screws are being operated. The relay panel is mounted to the side of the breaker on open-type equipments and in the cover of subway-type equipments in order not to decrease accessibility to the breaker and mechanism.

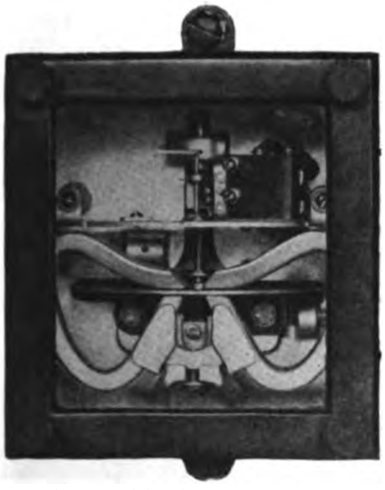
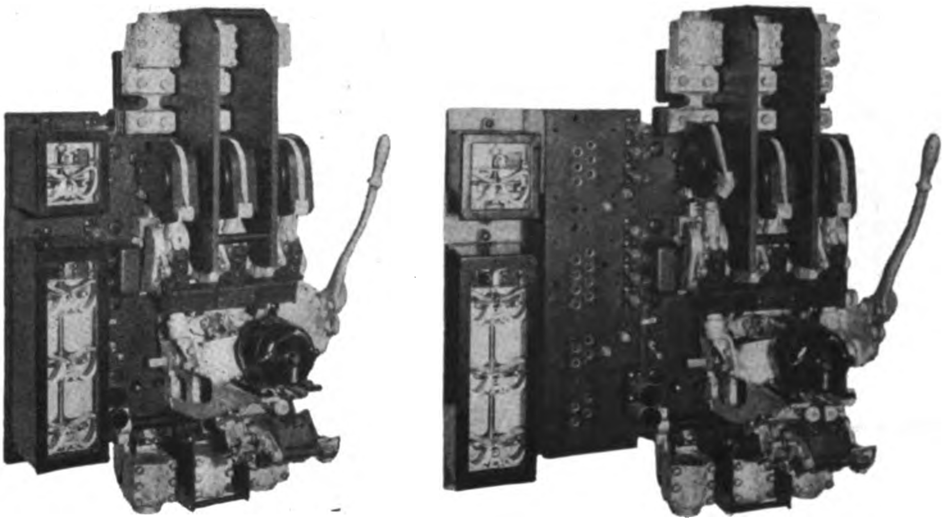


Fig. 61. General View of Single-element Phasing Relay for Use with A-c. Network Protector to Prevent Possible "Pumping"

The next interesting feature is the use of silver-to-silver main current-carrying contacts on the breaker, with separate steel springs for contact pressure instead of the conventional laminated copper brush. The laminated copper brush has a definite temperature limit above which it cannot be operated safely. If this temperature is exceeded the brush will soften and lose some of its pressure, which will further increase the heating and raise the temperature. The effect is accumulative; and if continued long enough will result in permanent damage to the breaker. Copper also oxidizes readily in air; and the oxide has poor electrical conductivity. The higher the temperature the more rapid is the oxidation. This effect also, with respect to the breaker contacts, is accumulative in that the more oxide on the contact surfaces the more pronounced is the heating; and the more the heating the more oxide is formed. Likewise, if this is continued long enough the breaker will be permanently damaged. For these reasons the conventional laminated copper brush is not operated above a total temperature of 70 deg. C. which at 40 deg. C. ambient permits a 30-deg. rise.

There are several good reasons why network protectors should have a much greater permissible operating temperature than 70 deg. C. The first that may be mentioned is that the protectors are sometimes mounted very close to the transformer terminals which may be at the oil temperature of 95 deg. C. The ambient temperatures in the vault cannot always be held down to 40 deg. C. Many occasions arise when it is necessary to carry considerable overloads for an hour or two even though extreme care has been taken to prevent such occurrences. The practice of burning clear secondary cable faults imposes severe heating conditions on the protector. It is therefore very desirable to design the protector to withstand these strains as well, or even better than the transformers. This does not mean that guarantees can be made for such conditions; but that the silver-to-silver contact construction withstands them much better than the laminated copper brush. The subway enclosing cases greatly increase the heating because of the dead air in the box. Then, from considerations of cost, weight, and space, it is desirable to operate at higher current densities and, consequently, higher temperatures. The silver-contact construction permits the application of a 1200-amp. breaker at about the weight, space, and cost of an 800-amp. breaker with laminated copper brushes.



(A) (B)

Fig. 62. Three-pole 2000-amp. Non-submersible Network Protector of Motor-operated Type, with (A) removable barriers between main poles and relays mounted on separate panel at side of breaker panel and (B) with relays removed showing spring-jack type relay terminal receptacles and one arc chute raised to show contact construction

Higher operating temperatures are permissible with the newer type of construction because of the lesser effect of silver oxidation in increasing the contact resistance as compared with copper; and because the strength of the steel springs, and therefore the contact pressure, remains practically constant up to temperatures far in excess of those at which the copper-brush laminations would anneal and thereby give decreased contact pressure. The silver contact has little tendency toward an increase in contact heating throughout indefinite operation at temperatures in excess of those deemed safe for the copper-brush type. This fact has been clearly demonstrated by complete tests and wide operating experience in other fields with this type of construction.

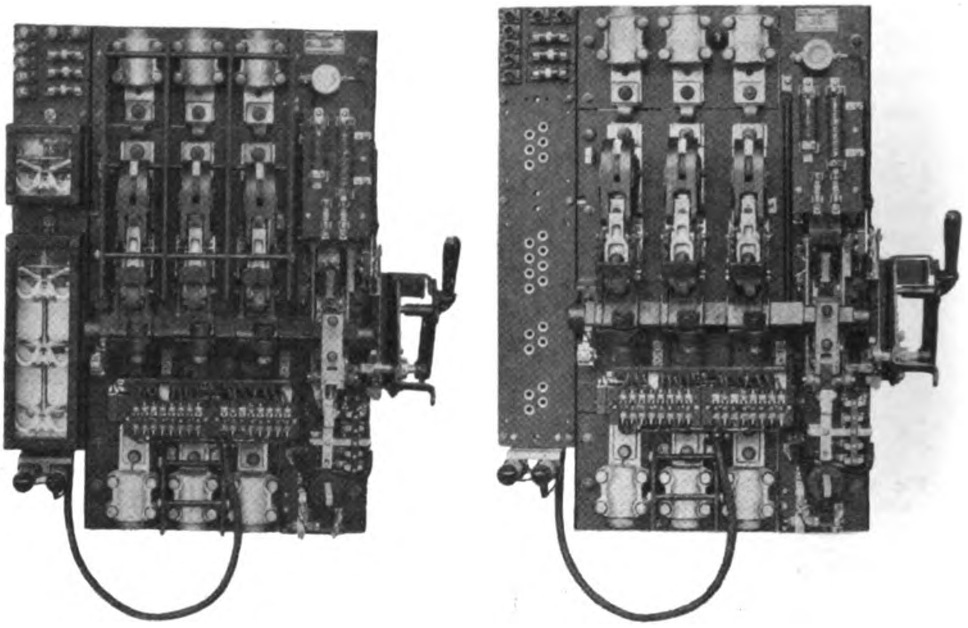

(*A*) (*B*)

Fig. 63. Three-pole 1200-amp. Non-submersible Network Protector of Solenoid-operated Type, with (*A*) control relays and indicating lamps mounted on separate panel to left of main breaker panel and (*B*) main barriers and relays removed showing spring-jack relay terminal receptacles

In actual operation it proved desirable to accomplish the tripping of the breaker by an a-c. shunt trip instead of an undervoltage device because the latter would operate on system disturbances. If the undervoltage device were designed to hold in at extremely low voltages, the current and losses at normal voltage would be excessive. The shunt trip was developed to operate on a voltage range of 26 to 230 volts. The coil is connected from phase to phase so that all single line-to-ground faults, which are the more numerous, would give at least 115 volts. On three-phase or phase-to-phase short circuits, the reactance of the transformer is depended upon to furnish voltage on the occurrence of high-tension feeder faults and the arc voltage, which is never less than 30 volts and usually around 75 volts, for low-tension faults. Devices now being manufactured will trip on less than 20 volts with a large number going lower than 15 volts.

Solenoid and motor-centrifugal mechanisms are used. The solenoid designs are fast in operation and require about 100 amp. inrush current. The motor mechanism is somewhat slower and smoother in operation and requires about 30 amp. inrush current for the higher ampere ratings. The motor mechanisms are much smaller than those previously developed for oil circuit breaker applications.

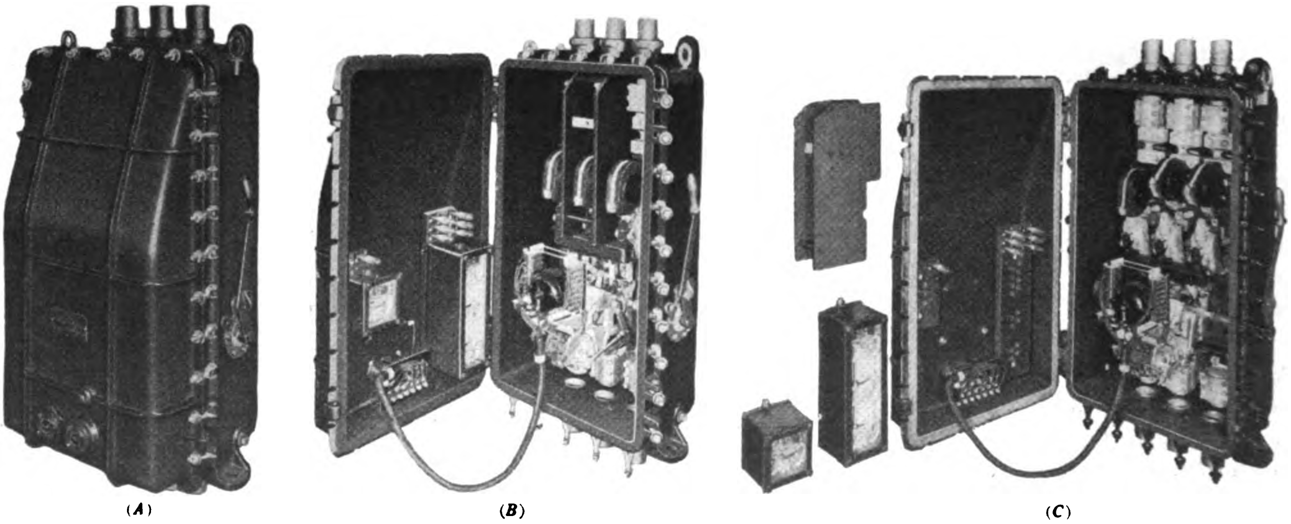

(*A*) (*B*) (*C*)

Fig. 64. Three-pole 1600-amp. Submersible Network Protector of Motor-operated Type. (*A*) External view, showing details of cast aluminum alloy enclosing case; (*B*) view with cover opened, and (*C*) with cover opened, relays and barriers removed, and arc chutes raised

For the applications where submersion of the equipment is probable a water-tight enclosing case is used to house the protector. For the solenoid-operated devices, which are built in the smaller ampere capacities only, the case is fabricated from copper-steel boiler plate. Since this is a magnetic material, it is found necessary to use non-magnetic end-plates where the cable conductors enter and leave the case. In the breakers of larger capacities, which are of the motor-operated type, it was found more desirable to use cast aluminum alloy. This construction allows a substantial reduction in the overall weight of the unit.

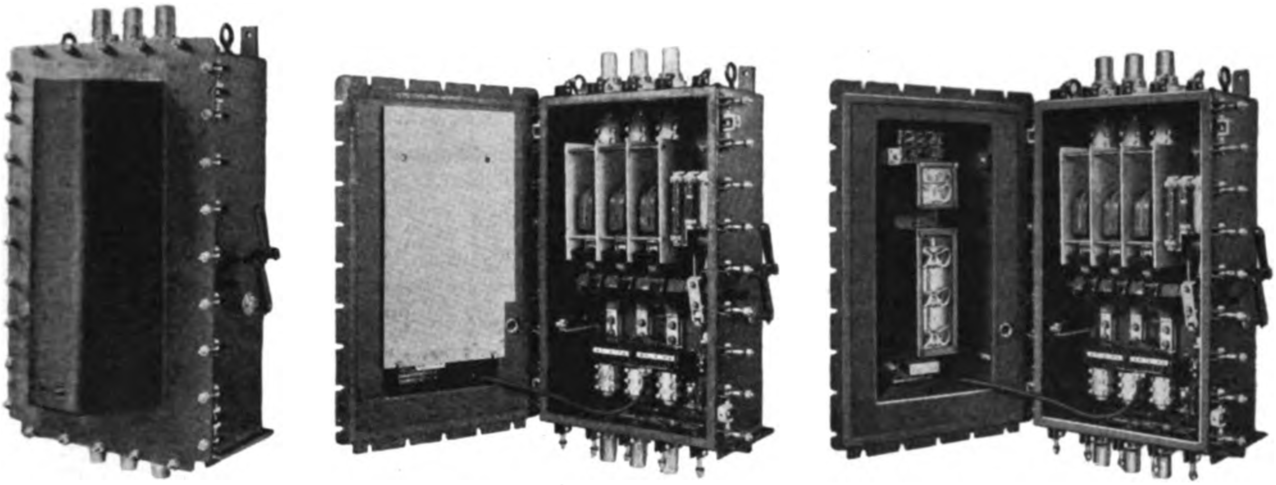

(A) (B) (C)

Fig. 65. Three-pole 800-amp. Submersible Network Protector of Solenoid-operated Type. (A) External view showing welded steel plate enclosing-case details; (B) view with cover opened, and (C) with cover opened and relay protective barrier removed

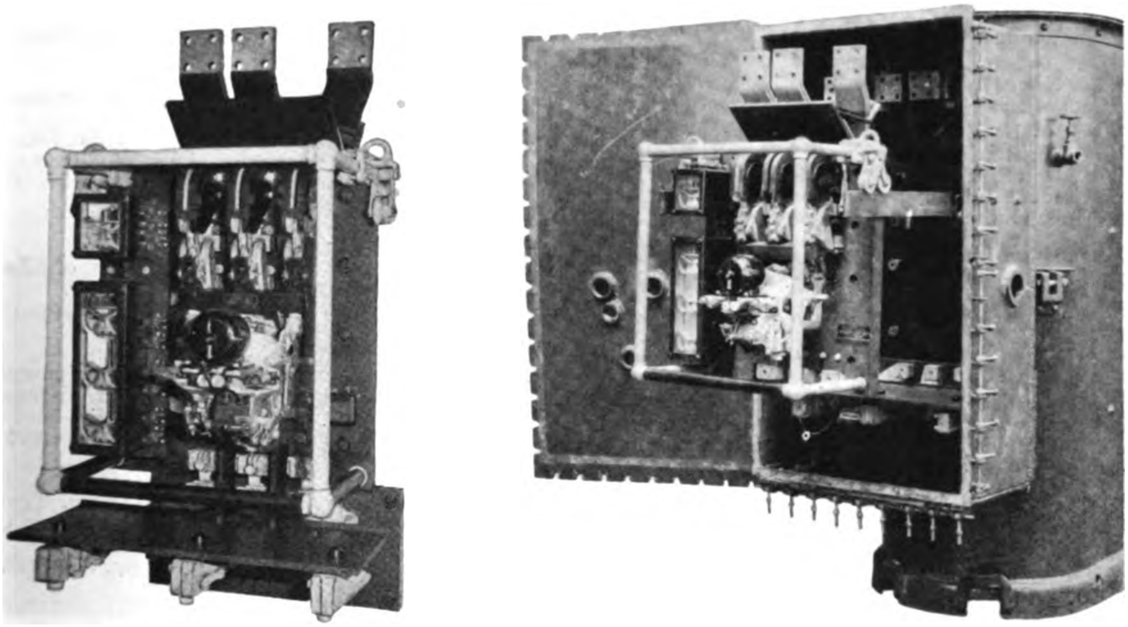

(A) (B)

Fig. 66. (A) Special Three-pole Network Protector of Motor-operated Type for Mounting in Low-voltage Pothead of 500-kv-a. Three-phase Subway Transformer as Shown in (B)

In the higher capacities the electrical loss in magnetic cases is appreciable, adding to the protector heating. The aluminum alloy also has superior heat-conducting qualities which result in more efficient conduction and radiation of heat from the breaker unit.

In either type of enclosing case provision is made for wiped-type waterproof cable entrances and external operating handle, indicating lamp lenses, and a clear glass lens for reading the mechanism operation counter. The joint between the case and cover is rendered water-tight by means of Vellumoid gaskets. Covers are arranged to hinge from either side and are sealed by means of hinged bolts. Pipe plugs are placed in the lowermost portion of the cases to facilitate draining water in case of leakage. These also furnish means of testing the devices for leakage after submersion without the necessity of opening the case cover. Similar plugs are provided for conduit connections in case control leads should be desired external to the protector housing. The case is furnished with lugs for wall mounting; and lugs are provided also on the bottom plates for mounting on horizontal supports such as I-beams or channels.

(*Concluded*)

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Arc Welding

Present Status of Structural Steel Welding. F. T. Llewellyn.
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(Abridgment of a paper read before the American Iron & Steel Inst. Serial.)

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High-Speed Circuit Breakers for Railway Electrification from the Design Point of View. H. M. Wilcox.
A.I.E.E. Jour., Dec., 1928; v. 47, pp. 896-900.
(Abridgment.)

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Iron & St. Engr., Dec., 1928; v. 5, pp. 513-417.

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Fans

Fan Types and Applications. H. F. Hagen.
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("A concise statement of the principles governing the selection of the type of fan for a particular kind of service.")

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Propulsion Circuits of the *U. S. S. Lexington.* Edgar Kranzfelder.
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(A lengthy paper with tabular matter, diagrams, etc.)

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Am. Weld. Soc. Jour., Nov., 1928; v. 7, pp. 7-83.
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Illum. Engng. Soc. Trans., Nov., 1928; v. 23, pp. 1051-1070.

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(Pertains to switching requirements in steel mills.)

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(Abridgment.)

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(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.*)*

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Construction of Alignment Charts. George W. Swett. 92 pp., 1928, N. Y., John Wiley & Sons.

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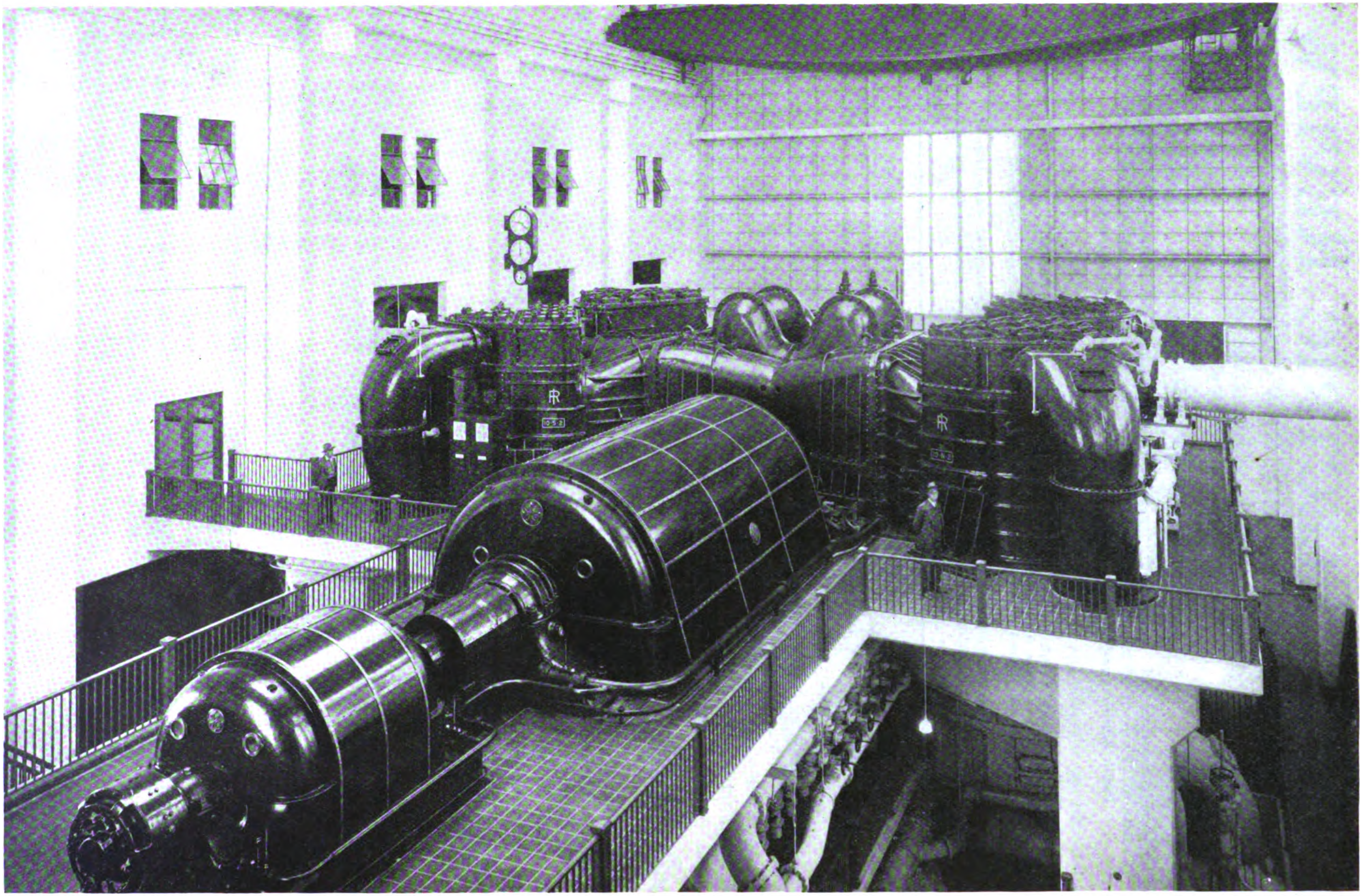

NINETY-FOUR THOUSAND KILOWATTS IN TANDEM

Tandem-compound turbine, 90,000-kw. main generator, and 4000-kw. service generator now operating in the Long Branch Station of the Southern California Edison Company. A photograph of this turbine-generator during its installation was shown on page 7 of our January issue. A duplicate unit for the same station is now being built

GENERAL ELECTRIC REVIEW

Vol. 32 April, 1929 No. 4

AVIGATION OR NAVIGATION

Is there such a word as Avigation; if not, ought there to be? If the word Navigation denotes the steering, directing or managing a ship, do we not need some word to describe the steering, directing, or management of our "birds of the air"?

We publish in this issue an article dealing with the problems involved in making a suitable magnetic compass for avigation, and in subsequent issues we hope to deal with Dr. Alexanderson's altimeter, and such other devices as pressure gauges, etc., which are necessary to guide, direct and manage our airships. With the perfection of these devices the science and art of Avigation should be much improved.

A reliable compass is an absolute necessity now that avigation has become an established fact, and is fast becoming an integral part of our economic life, and a reliable means of determining the altitude of machines in the air is an imperative necessity. It will be realized that a pressure gauge that will always function with accuracy is of scarcely less importance when we remember the discomfiture that has been caused some of our daring adventurers in the past by the failure of their gauges.

The problem of avigation in a three-dimensional sea of air will ever be harder than the problems of nagivation on a two-dimensional surface of water. The reason why man sailed on the seas so many centuries before he flew in the air is largely to be found in the difference of density of these two media.

In solving our newer, and harder, problems of avigation we have a rich storehouse of knowledge to draw on, but some of the problems are so specifically new that much research work will be necessary before their solution is achieved.

The science of Navigation took an extraordinarily long time to develop, and if any one tried to give credit to those who were preëminent in the solution of the many problems involved, he would have to delve deep into the history of science. He would find that no individual pioneer was far in advance of his contemporaries; and, indeed, this statement is true of all intellectual achievements, which are always slow in their growth, and gradually become more perfected by the united labor of many workers.

In the Western World, before the introduction of the mariner's compass, the art of Navigation was confined to the absurd limits of having to keep within sight of land. The Easterners could, and on occasions did, make long voyages on the China Sea and over the Indian Ocean because they had observed the constant direction of the monsoons.

The only way man, floating through space on a small sphere which forever revolves on its own axis as it makes its perpetual journeys round the sun, can know *where he is* on that globe, is by observing his relative position to the heavenly bodies, and by having an accurate means of determining time. The science of Navigation resolves itself into knowing *where you are*. Therefore the science of Navigation owes its greatest debt to those wonderful old friends of ours, whom we never weary of reading about, who developed the science of practical astronomy, which must ever be remembered as the father of Navigation as a science. Almost all of these old friends of ours worked under the dark cloud of suspicion, in constant fear of persecution and prosecution. What would have been the use of all our wonderful old cross-staffs, astrolabes, sextants, and other nautical instruments without the knowledge they so courageously and laboriously accumulated and handed down to us?

Hipparchus, a century and a half before the Christian Era, in his observatory at Rhodes, made the first catalog of the stars; and thus, although unknowingly, laid the corner stone for the science of Navigation. A century and a half after the dawn of Christianity, Claudius Ptolemy, although he held the geocentric theory, among many other notable contributions to astronomy, discovered the principal inequalities of the moon's orbit and left to posterity his invaluable Almagest.

Then there were ages of darkness; and Bagdad—the Bagdad of the Arabian Nights—the capital of Arabia, became the center of scientific thoughts and activities.

We have to wait until the 13th century for the next stone to be laid in the foundation of the science that led finally to Navigation becoming both a science and an art. It was then that Alphonso X, sovereign of Castile, at great expense, published the new astronomical tables that had been computed by the most distinguished professor of the Moorish universities.

It is only now that we come to the better-known part of history when Nicholas Copernicus, after 36 years of intense study and labor, observation and calculation, propounded *his* heliocentric theory. The writing, printing, and publishing of his glorious contribution to human knowledge entitled, "On the Revolutions of the Celestial Bodies," is a romance in itself. Copernicus was born in 1473 and died in 1543. He was on his deathbed when the long-waited-for first printed copy of his book was placed in his hands. He touched it and felt it—but never read a word. It is said that the book dropped from his hand to the floor as he drew his last breath on earth, and that at that moment the veil of ignorance also dropped from the eyes of man—that the death knell of the dark ages was sounded and the Renaissance was ushered in.

Three years after the death of Copernicus, that is to say in the year 1546, that magnificent, but extraordinarily temperamental creature, that strange compound of bombast, genius, infinite patience and skill—the sometimes ludicrous, but the more often lovable, Tycho Brahe, was born. What a checkered life he led, sometimes uplifted and honored, sometimes disgraced and degraded; but that is another story. In his forever-famous observatory of Uraniburg—the City of the Heavens—Tycho lived, entertained kings, princes, and men of letters; worked, loved and quarrelled, but he gave to the world the first truly great and marvelously accurate map of the heavens. Tycho died in the year 1601, but after he had been driven from the child of his own creation—his island home, the City of the Heavens—and before he died, he met, worked with, always idolized, and often quarrelled with, Johann Kepler.

That these two men should have met is one of the extraordinarily fortunate coincidences in the world's history and the most fortunate circumstance for the art of Navigation. Tycho gave Kepler his forever famous map of the stars and from this data Kepler made those three great astronomical discoveries that gave a law unto the heavens, and numbered his name among the immortals, *viz.:*

(1). That Mars revolved round the sun in an elliptical orbit in one of the foci of which the sun himself was placed.

(2). That the radius vector, or line joining the sun and planet, describes equal areas in equal times.

(3). That the periodic times of any two planets in the system are to one another as the cubes of their distances from the sun.

Kepler was born in 1571 and died in 1630.

The next great light in the history of practical astronomy was Galileo Galilei, who was born in 1564, and it is worthy of note here that three of the most remarkable men in history of astronomy were contemporaries. Galileo was the contemporary of Tycho for thirty-seven years and of Kepler for fifty-nine years of his life.

Galileo is known to the world as much for his hostility to Aristotelian philosophy, his revolt against authority, and his contribution to mechanics and optics, as he is for his notable contributions to astronomy. He was the first to make and use a telescope in the service of this science. He discovered the satellites of Jupiter, and had remarkably shrewd ideas as to the laws that govern the universe. And be it ever recorded to his credit that he propounded a means of determining longitudes by observing the eclipses of Jupiter satellites. His book, "The System of the World of Galileo Galilei" (1630 to 1632), that got him into trouble with the Church, and into the clutches of the Inquisition, was one of those great contributions to the world's knowledge, and will ever be remembered, together with Copernicus' "On the Revolutions of the Celestial Bodies" (1543), and Kepler's "New Astronomy" (1609), and "Harmony of the World" (1619), as a forerunner of Newton's marvelous and epoch-making work, "The Mathematical Principles of Natural Philosophy" (1687)—so commonly called, with a strange compound of respect, admiration and something akin to affection—the "Principia."

Galileo Galilei died in 1642, the same year that Isaac Newton was born, and thus the torch of human knowledge that was finally to help us in solving our problems of Navigation was handed on from one generation to another, growing more brilliant with each succeeding "Torch Bearer."

With a knowledge of the work of Copernicus, Tycho Brahe, Kepler, and Galileo Galilei, Newton propounded his immortal theory of universal gravitation, and wrote his no less immortal three laws of motion.

Now that the old geocentric theory of the universe had been killed forever, and the heliocentric theory had been established, man took more courage and became more ambitious. Ambition, beyond any dream that would have been tolerated in the "old days" when superstition reigned supreme, was born when knowledge displaced fear by hope, inquiry for authoritative dogma, and search and research for blind belief. We can never estimate the debt that we owe to these courageous "Torch Bearers." It was upon the foundations that they laid that the whole nautical world of that day based their study of how to determine latitude and longitude at sea.

The Royal Observatory of Greenwich was built in 1675 for the advancement of Navigation and Nautical Astronomy. It was built by the order of King Charles because—"he startled at the assertion of the fixed stars' places being false in the catalog, and said with some vehemence he must have them anew observed, examined and corrected for the use of his seamen."

Old Flamsteed, that rheumatic, and therefore crusty, old Episcopal parson, who because of his meager salary had to preach sermons, christen babies, and bury corpses, as well as make astronomical observations, was the first Astronomer Royal. He was often a thorn in the flesh of Newton, but with all his faults and with all his handicaps he did make most valuable observations and records.

No further steps seem to have been taken in this important matter till the 25th of May, 1714, when several captains of her Majesty's ships, merchants of London, and commanders of merchantmen, presented a petition to the House of Commons, setting forth that "the discovery of longitude is of such consequence to Great Britain, for safety of the navy, for merchant ships, as well as of improvement of trade, that for want thereof many ships have been retarded in their voyages, and many lost; but if due encouragement were proposed by the public, for such as shall discover the same, some persons would offer themselves to prove the same before the most proper judges, in order to their entire satisfaction, for the safety of men's lives, her Majesty's navy, the increase of trade, and the shipping of these islands, and the lasting honor of the British nation."

The outcome of this petition was the appointment of a large committee which rendered its report to the House of Commons on June 7, 1714. Sir Isaac Newton was on this committee. His remarks are far too full to quote here. But we attempt to give the mere gist of them as follows:

"That for determining the longitude at sea there have been several projects, true in theory, but difficult to execute.

"1. One is by a watch to keep time exactly; but, by reason of the motion of the ship, the variation of heat and cold, wet and dry, and the difference of gravity in different latitudes, such a watch hath not yet been made.

"2. Another is by the eclipses of Jupiter's satellites; but, by reason of the length of telescopes requisite to observe them, and the motion of a ship at sea, those eclipses cannot yet be there observed.

"3. A third is by the place of the moon; but her theory is not yet exact enough for that purpose. It is exact enough to determine the longitude within two or three degrees, but not within a degree.

"4. A fourth is Mr. Ditton's project; and this is rather for keeping an account of the longitude at sea, than for finding it, if at any time it should be lost, as it may easily be in cloudy weather. How far this is practicable, and with what charge, they that are skilled in sea affairs are best able to judge. In sailing by this method, whenever they are to pass over very deep seas, they must sail due west or east, without varying their latitude; and if their way over such a sea doth not lie due east or west, they must first sail into the latitude of the next place to which they are going beyond it, and then keep due east or west, till they come at that place."

The outcome of this committee work was "That it is the opinion of this committee that a reward be settled by Parliament upon such person or persons as shall discover a more certain and practicable method of ascertaining the longitude, than any yet in practice; and the said reward be proportioned to the degree of exactness to which the said method shall reach." This resolution was unanimously adopted by the House.

Quoting again from Sir David Brewster's Life of Sir Isaac Newton published in 1855, the source of our other quotations: "After the death of Newton, the problem of finding the longitude at sea became a subject of general interest throughout Europe. Various acts relating to it were passed in England. In 1726, our countryman, John Harrison, produced a timepiece of singular accuracy, and, after many trials, in one of which it gave the longitude within 10′ 45″ of the truth, £10,000, half the reward offered in Queen Anne's Act, was adjudged to him; and the other half promised when an equally good timepiece, upon the same principle, should be made by himself or others. Mr. Kendal, who was appointed by the Board to make such a watch, succeeded so completely that after it had been round the world with Captain Cook in the years 1772-1775, the second £10,000 was given to Mr. Harrison."

We have endeavored to show as briefly as possible what a long-drawn-out business was the discovery of how to determine correctly the longitude at sea, and how we are indebted to many almost unknown, and some almost forgotten men, upon whose work the science of Navigation rests. And this determination is only one factor in the art of Navigation. The history and development of the mariner's compass, the origin of which is lost in antiquity, would be a longer story.

When we consider how long has been the history of the development of our marine navigating instruments, we wonder if the instruments for airships have not also a long development period to go through before they are perfected. It is well sometimes to remember Tennyson's words: "Science moves, but slowly, slowly, creeping on from point to point."

However, we believe none of the problems of aërial navigation, or avigation, are insurmountable, and that in the reasonably near future our compasses, altimeters, gauges, beacons, direction finders, and possibly the means of piercing fog, will be developed to a stage where man may fly safely through the uncharted cloud lands of the sky, and land with precision in all kinds and sorts of weather whensoever and wheresoever he will.

J. R. H.

Chemistry and Electricity

By **DR. HARRISON E. HOWE**
Editor of Engineering and Industrial Chemistry

(A lecture delivered before the Midwinter Convention of the A.I.E.E. at New York)

TO one who has spent some time trying to popularize a certain type of truth, the present occasion is rather terrifying. I feel the pressure of accomplishments here. I wondered why a mere chemist should be thrown into electrical lines. I have concluded that perhaps I was given this honor, because after all I doubt if any combination of scientists or fields of scientific activity have accomplished more for society than chemistry and electricity working together, although possibly now that chemistry has come to the aid of biology in aiding medical science, still greater things may be accomplished in that field. Certainly I think it is easy to show that together they are responsible for much of the material satisfaction and benefits of our present age, and that much can be traced to these two working in harmony.

It is also a good illustration of the ideal business transaction where both parties to a trade profit from what has been done, for while chemistry claims to have contributed something to the progress of electricity, chemistry is happy to acknowledge its great debt to what electricity has done. So, it seems to me, we are truly team mates in all sorts of progress, both in science and industry.

That is further shown by the fact that much of our progress in science, both fundamentally and industrially, has come from the great laboratories established in the electrical engineering field. We are fond of saying in chemistry that in addition to the progress made in the chemical industry, thanks to research, the best examples can be taken from the electrical industry, which is also comparatively young, and where great progress has also been made. Indeed, one might spend more time than I have at my disposal this evening and only mention a few of the prominent contributions that have come from the laboratory. Let me mention a few names that are familiar to many of you, that we know as men who have contributed largely to scientific progress in chemistry quite as much as in electricity: Davison, Germer and Elmore. Those who follow scientific literature know that very many learned and very many valuable contributions have come from the Bell telephone laboratories.

Chemistry and electricity have many things in common. I think a quotation I shall read from Sir William Bragg applies equally well to both of these activities. This is very short, and I think very well puts things that are familiar to most of us. He was speaking of the relation of pure science to industry and said:

"It is easy and fascinating to suppose a new invention is found as complete and clean as a nugget of gold, as unexpected and as unconnected with its surroundings, and finally, as readily convertible into cash. The truth is very different. Science does not increase by the constant addition of new facts to old as libraries or as museums by the addition of new specimens and curios. Science grows like a tree which shoots out new branches continually, and at the same time strengthens the old, and always growing higher into the light. Like the tree, science needs wise cultivation. The nourishment of the tree and its pruning have their counterparts in science. In both, the fruits come as the reward of skill and labor. The fruits of science are first seen when they are brought to market, and as vaguely supposed they were picked up somewhere and somehow in the condition in which they appear. Perhaps they were made by the man who carries the basket. It is not realized that the fruit comes at the end of a long process, and even a little application of science may be the result of unseen labor and growth for many years. It is not as easy to develop scientific results as to grow an orchard. The growth of science is not so much under our control as the growth of nature."

Certainly, electricity has contributed much to the fundamental theories in chemisty. I might say that the discovery of radium has been a very real contribution.

In trying to compare these things, I naturally turned to those who knew much more than myself and asked what they thought might be stressed here this evening. Our good friend Dr. Whitney, whom I am fond of describing as the General of Research, wrote me this. I had been talking to him sometime ago about the importance of analytical chemistry. He said: "In Chemistry—and it is true of electricity—we were first mere analysts. It took a long time to get much beyond questioning the composition and natural action of things. Only a small fraction of the work was productive in the sense of synthesis. In fact, in the very early days each national group devised its own names for the analytical products each thought it had found. We had as many analytical ideas as there were analyses made, and all expressed in different tongues. Naturally, all the tongues first attributed everything, from the chemical elements to the meteorological elements, lightning, to unanalyzable gods, and so, Mercury, an element, and Thor, for thunder, for example.

"Synthesis based on analysis is still terribly young, and nowhere is it more evident than in the lives we lead. That we are copying the attributes of a Creator with the things which are already created is growing clearer. We do not create a thing, neither element nor law, but we put them together with more and more light or analytical knowledge. Thus, the tendency is now to simplify all world analysis toward quick communication by electrical means so as to speed up the creative or synthetic work for which there is no limit in sight. On the contrary, every new step opens more than one new possibility. Chemistry and electricity have both been analyzed down to the same little-understood units, but this is only a passing phase."

One might go on at some length comparing, or rather showing, in what respect each has contributed to the other of these great endeavors to the fundamental work, but I think, as Sir William Bragg says, most of us see these various inventions when they come to market in some sort of a market basket.

Any one of the several things I shall mention from now on might easily be the subject of an entire evening's discussion or a symposium, if you like.

I think I will begin with electrolysis of salt, and tell you what it really means to us as individuals. Of course, there are other ways of making caustic, but they are not nearly as efficient or as satisfactory as the electrolysis of salt.

What do we do with caustic soda? To begin with, soap might be mentioned as something presumably familiar to all present. Then, caustic soda is used in the manufacture of soda pulp and mercerized cotton. That brings us quickly to one of the romantic things in chemistry, in which a great deal of caustic is used. I refer to the rayons of the day. When you recall that in 1928 we produced probably nearly 100,000,000 pounds of rayon in the United States alone, besides importing a great deal, you will get an idea of what was required. In 1929, we shall make 125,000,000 pounds of this particular chemical fiber in our own country, and for this no less than 200,000,000 pounds of sodium hydroxide will be required as one of the chemical raw materials.

Great progress has been made in recent years in rayon. We begin with things like these—pulps that are made from various sources. [Samples exhibited to the audience]. Here we have some samples of the alpha cellulose made from the spruce tree. Here is one of the hemp. And here is one made from the esparto group that grew in Africa and was made in this form by a chlorine process.

The man who invented artificial silk thought he had to imitate the silkworm. Now we know that all we need is a pure form of cellulose, and these are some of the samples. Or if you prefer, here is another type of cellulose. Much is made from cotton linters, of which this is a sample of the material. Then, the next thing we must do is to again apply chlorine and other types of chemicals in giving a pure fiber of this sort. As has been said, the diversity of products from fibers of this sort is so great, whether the fiber comes from the tree or the grasses or the cotton, that at this stage one does not know whether it is going to become literature or lingerie.

Some of the work that has been going forward has been accomplished, thanks to what electrical science has given us; for in this improvement in the rayons themselves we have the x-ray method of analysis largely to thank, because you have given us in the x-ray a wonderful tool for research. As many of the gentlemen here know, things may be alike in physical and chemical analysis and still not be alike in their behavior when it comes to manufacturing processes.

As for the final products, I need scarcely show you these; all you need do is walk down the avenue and look in the windows. These indicate what can be done in the way of dying the material. Here are rayon velvets that have been dyed, and here are some satins and permanent moires, knit goods, and all sorts of things, showing to what extent this new material is making headway and requiring more and more raw materials that involve electricity in their manufacture. We have reached the point where the question as to whether or not cotton continues to be king will be settled in the research laboratory. And because of the difference in attitude on the part of the two groups, I am putting my bets on the rayon rather than on the cotton industry.

I believe it is true, as someone has said, that it is far better to know the fixed attitude of a corporation toward research than it is to know its fixed assets, if one is deciding where to place his investments.

Let us go still further with this application of sodium hydroxide to cellulose. Perhaps you are familiar with the artificial sausage casings that are now being made in sizes to take care of the "hot dog" at the rate of 70,000,000 per day. Here again we have a great consumption of sodium hydroxide in the manufacture of these sausage casings.

Just a moment on the research side of this: Think of a group of men working for a number of years to produce this really remarkable tube of viscose and then losing two years in production because they wanted to use the new casing in the very same way that natural casings are used on sausage stuffing machines, namely, wet. And so, for two years they experimented with oils and fats. Having tried everything and failed, one of the men suggested that they use them dry, which they found was just exactly the way to use them. So, you musn't always be guided by your previous experience with an old material, when you produce an equivalent or better material of this sort.

Then too, you may recall that it is thanks to this type of casing that we have been able to produce for the consuming public the long-desired nude sausage. There has been a great demand for a sausage without a casing, and while we began to brag about putting all the sausages into cotton shirts, it was soon found that they were not affected by smoking as are natural casings, that the sausage meat would stand enough to allow it to be handled, cooked and served without the casing.

If you don't like "hot dogs" and you want some of the Italian sort of sausage, those casings are also made. There appears to be no physical limit as to what can be prepared.

Here are some sheets of celophane, which has become so popular as wrapping material, and is available in all sorts of colors. These are only eight thousands of an inch in thickness and they are reconstituted cellulose, made literally by the millions, and making possible again when one considers this whole chain of things a large number of types of products, because they offer a wrapping that is quite superior to anything we have had heretofore. These materials are also made moisture proof so that one of these days, I think, we shall find our beefsteaks and chops and fish dispensed to us in a quick frozen condition through slot machines that will be kept cool by means of dry ice and materials of that sort.

That is not a fanciful dream. If I only had an opportunity to sell a little fish here, I could tell you a great deal of what is going on in merchandising materials that heretofore have been considered perishable. We have made with electricity and chemistry these sheets which are only eight thousandths of an inch in thickness in tremendous quantities, an accomplishment, I think, that borders very closely on some of the things that have been done in other lines of engineering.

The Aluminum Company of America began a few years ago the problem of producing a really pure aluminum. Most aluminum we buy is under ninety-eight per cent pure. Here is a bar that is 99.95 per cent pure—even purer than Ivory soap. In the laboratory they have made it 99.96 per cent pure. This work is undertaken to enable them to really learn what aluminum is. A great deal has been done toward producing some sort of protective coating, but until this alloy was sprayed with this very pure aluminum nothing successful had been found. Just as physicians will sometimes not admit that a cure has been found for a particular disease, one cannot say that this problem has really been solved. One can say, however, that for two or three years bars that have been protected with this metal have withstood the most severe tests.

Calcium carbide should be mentioned as another contribution of electrical energy in the chemical industry, and it is not only useful in itself but is the starting point in a very long chain of products such as acetylene and cyanide and a lot of others that might be mentioned.

Another very minor field but nevertheless very important to the chemical industry has been in the installation of the necessary control apparatus. I remember very well in the early days in the beet sugar industry that we had to have a man sit by a valve and turn it off and turn it on. I recall that the superintendent came upon the man one day fast asleep. He was very angry, of course, and asked him what he was being paid. The man at once named a figure $5 higher than he was actually getting. The superintendent went back to the factory and told them that hereafter he should be paid a figure which he named which really amounted to a $3 raise for the fellow. So, while he was sitting there watching the valve, he wasn't so dumb after all.

But, today, we don't have to do that, thanks to the application of the vacuum tube and other things that electricity has provided. We are enabled through very slight differences in temperature, in pressure, even in colors, in thickness and in moisture to do much of this work that heretofore has had to be done by hand.

I really think that in many industries the application of these automatic electrical control devices is held back not so much by what can be done by these devices, but by the scarcity of men who are able to keep them in order and get the most from them.

I mustn't spend all the time relating what electricity has done for chemistry. There is a slight debt on the other side. I want to mention that.

To begin with, just to further advertise industrial engineering chemistry, may I refer you to an article* by Mr. Stoll, a vice president of the Western Electric Company—a short article which you will enjoy reading very much. I shall not repeat here the points which Mr. Stoll so admirably makes in that article.

I think we might begin by mentioning electroplating and electrolytic refining of metals which has meant so much to the electrical industry. I have this material to remind me of chromium, which has been one of the latest editions. You see it on all the automobiles. Perhaps you have not read that it is going to reduce the cost of manufacturing our paper money, though I suppose in that industry the saving will not be passed on to the ultimate consumer. Thanks to the application of a thin skin of chromium on the hand-engraved steel plates, it is possible to obtain four or five times as many impressions from the single plate as heretofore; and when the edges wear

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*The article named by Dr. Howe was "Contributions of Chemical Science to the Communications Industry," by C. G. Stoll, *Industrial and Engineering Chemistry*, October, 1927, pp. 1132-1135.—EDITOR.

down the chromium can be stripped off and another plating added and still further runnings obtained.

Here is a sample of a screen that is entirely coated with electro-deposited rubber. This is in the stage between the laboratory and the commercial development. As you know, in chemistry as in everything else, there are the four stages. We begin with the laboratory; we then go into the semi-commercial stage; we then go to the plant, and eventually we go to the plant that does not have its figures in the red; and then we go to the commercial stage. This particular work is between the second and the third stage. This shows a very great progress. And if you want rubber in other forms, they, of course, can be had.

Here is a new type of filter cloth, which is a porous rubber and has a great many applications in the chemical industry, and perhaps it may have in the electrical industry. It is all rubber and answers the purpose where cloths will not do for filtration.

Here are some samples of what are called doublers in the shoe trade. These are latex-impregnated cotton fibers. They are put in this particular shape and have some rather unusual characteristics. There again I think you will find some real contributions coming along that will be of interest in the electrical field.

In metal refining, I am sure I do not need to go into detail with this audience concerning what has been done. Along with that should be mentioned the work that has been done by the metallurgist. This whole field of metals would be incomplete if we did not mention permalloy, which has come from Dr. Jewett's laboratory and which has meant so much to the communication industry.

Another contribution to which the chemical group is very proud is that of the synthetic resinoids of the bakelite type. Inasmuch as Dr. Baekeland did the prior work in this particular field, I think it is fair to remind you of his contributions by some of these exhibits.

Here we have the familiar switchplate which is now so rapidly displacing those made of metal. Seemingly, metal had always been used for this purpose and seemingly, it always would be. The brass switchplate could be made in any shape desired, with a variety of surface finish, and the cost to the ultimate consumer had been brought to a very low figure. Today, we have a different situation. The usual switchplate is now more apt to be made of an insulating resinoid material which the chemical laboratory has brought into being. Initially attractive in appearance, the new type of switchplate does not tarnish nor corrode in service; moreover, it is an insulator rather than a conductor like metal. There is good indication that the majority of the many millions of switchplates which are produced annually will now, and henceforth, be made of resinoid instead of metal.

Hundreds of thousands of telephones of the so-called European type are now being installed in American offices and homes. The handpiece, the receiver-transmitter unit in other words, is made from bakelite molding material. As this audience may well know, the initial resinoid material, invented by Dr. Baekeland and a product of chemical research, has in this instance been molded with reinforcing and pigment material; after a few minutes in the press this finished accessory of modern communication is the result. That the material is thus producible in a form at once pleasing in appearance, mechanically strong, and electrically insulating, is a fortunate circumstance of the joint foresight of nature and research.

Here is another application of these resinoids in your industry. Not being familiar with the work of electrical engineering, I am going to read a brief but authoritative statement about this thing so I won't get it wrong.

"Such special insulating sleeves are made for the purpose of interrupting the metallic continuity along the lead sheath and connecting joints of underground electric-power single-conductor cables. When single-conductor cables are used on alternating-current circuits, such as single-phase or three-phase circuits, there is a transformer action between the current in the conductor and the lead sheath of the cable, resulting in induced voltages in the sheath. If the cable sheaths are bonded together in the usual fashion in each manhole, then the circuit of the sheaths is completed so that currents flow in the sheath, resulting in heat losses. These losses also in turn decrease the carrying capacity of the cable.

"Special connections have been evolved by several inventors and each one involves the idea of interrupting the metallic continuity in the manhole by inserting some insulating material in series with the metallic circuit, either on the sheath of the cable itself, or in the containing sleeve of the joint. With such arrangements, the induced voltage remains, but the electric circuit is interrupted so that the currents cannot flow, thus eliminating the heat losses and increasing the carrying capacity of the cable."

Of course, other things are made of this very attractive material. We have all sorts of gay things in different colors that are made for those who like gay things, and we have other materials of a very fancy nature that show what can be done with the molding material. All the work is done on the mold with great precision, regularity and saving of time, with a very handsome appearance without other finishing, embossing, engraving, and the like.

Another thing we might mention, of course, is the work that chemistry has done on transformer oils, and without any great elaboration you know what it has meant to the electrical industry.

Then too, we have the chemistry of the dry battery and the storage battery.

There is, of course, the Pyrex type of material, a type of material developed first, thanks to the electrical industry, when these people began to make a glass that would stand the severe punishment from the closed arc. By the time this glass was ready for the closed arc, the closed arc had been superseded by some other form of lighting. It had to go to the kitchen to get an outlet for a great production and to cash in somewhat on the experiment. Then, it came out of the kitchen to make possible the type of chemical control necessary during the war, and has become the leading glass of scientific purposes since that time. Now, it has been developed further in order to serve the electrical industry.

Unless you are really familiar with some of the problems in glass molding, it is difficult to appreciate what it means to make an insulator of this type for very high voltages; this being, of course, a multiple mold that enables manufacturers to cast this material of a very high fusion point that has the characteristic that you so much desire in the electrical field.

Here is one of those large insulators that has been sawed apart in order to give some idea of the complexity of its construction.

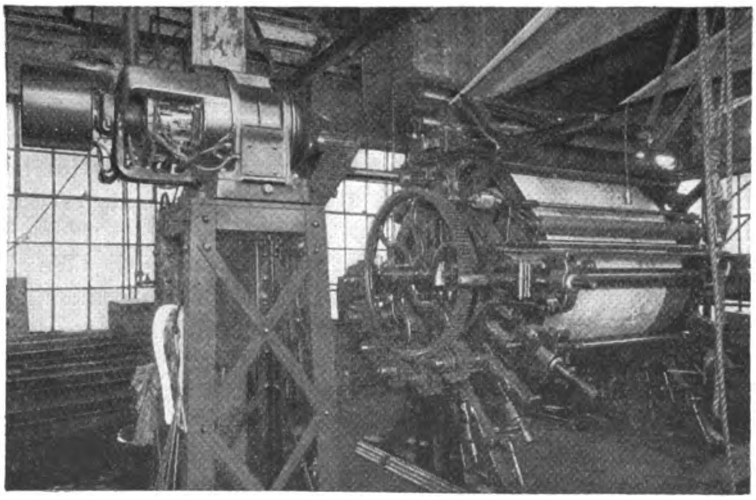
Then, we have these other things that are required where high frequency is involved, and these others are finding favor in the radio industry. These types are not the size, but are the types of insulators that are now being used by Commander Byrd in all of his remarkable broadcasting from the Antarctic.

We must also mention while talking about glass what has been done with the electric light bulb. In my youth, all of this had to be done by hand. Now, there are 450,000 electric light bulbs machine-made every day, which is due to the chemical control of the raw material that has the physical characteristic making possible that type of work. Then, the contribution of the frosted bulb is another thing from the chemical laboratory that has meant a great deal.

The material from which the new two hundred-inch reflector for the new telescope is to be made is a great achievement where electricity and chemistry together will join to produce something that will enable us to look still further into the unknown.

I think that you as electrical engineers, and perhaps, if I may be permitted to represent chemistry, we would agree that without us very much couldn't be done. I think in that connection, I ought really to just read you one or two other little quotations, particularly one from Goodyear, to whom we are very much indebted for the example he set as well as for the work he did. I think most people fail to remember that Goodyear worked at a time when people could be put in jail for debt—of course, we are all very glad that that time has passed—and that he accomplished much while being supported by the friends of his family; and yet he recorded this in his notebook: "Man has just cause for regret when he sows and no one reaps."

It was Aristotle who said what you find on the face of the National Research Council Building: "The search for truth is in one way hard and another way easy; for it is evident that none can master it fully, but each adds a little to our knowledge of our nature and from all the facts assembled there arises a certain grandeur."



Adjustable-speed A-c. Motor Applied to a Textile Printing Machine

What is Right in Industry

By OWEN D. YOUNG
Chairman of the Board of Directors, General Electric Company

(An address delivered at the invitation of Dr. Fosdick, at the Park Avenue Baptist Church, New York on Jan. 20, 1929)

ONE bright crisp day in the fall of 1905, David Shaver was driving down the long, winding, and only street in Van Hornesville. His conveyance was a one-horse lumber wagon with bottom boards and no box. David was standing on the boards, his long gray beard waving in the breeze, driving a horse that looked almost as old as he. Suddenly around a bend in the road a large motor car showed up. The old horse went over the stone wall and down into a hollow about ten feet below the road. The wagon and David followed. There was a mix up of broken harness and bottom boards and whiskers. The driver of the motor car seeing the catastrophe, stopped, looked over the wall, and solicitously asked, "Can I do anything for you?" David slowly disentangled his whiskers and answered, "No, I think you have done all you can for me this morning."

As I said, that was in the year 1905. Motor cars were just beginning to occupy our roads. At the same time here and there, sometimes without notice, big business began to show up around the bend.

There is a striking parallel between the two. Then motor cars were not very highly developed nor very reliable. Their drivers were likely to be men of adventure and of courage, frequently none too considerate of the old wagons on the road. Often they were quite unskilled; and then too the roads themselves were not very well adapted to the new machines. As time went on, the old horse-cab drivers became motor-cab drivers and they drove with something of the abandon and the carelessness with which they had driven the horses, not fully realizing that a 40-horsepower motor was a different thing from a one-lung horse. Now in 1905, my old friend David did not like motor cars. He had had his experience with them. He would have been glad to have shut them off the road altogether. But some years later I had the pleasure of taking him in a motor on what he described as the best ride of his life. Then he thought better of motor cars and finally he came to understand, as we all have, the great contribution which they have made to the health, wealth, and happiness of all people.

It was much the same with big business. Sometimes its drivers were reckless; sometimes they were highly careful and conscientious, but the old horses of business were not yet adjusted to the new device. Dire prophesies were indulged in as to what would happen if large business units were to be permitted. It was said the masses of the people would become their slaves. The business machines have become better adjusted through a quarter of a century. The drivers of them have become more skilled. In a sense, they are people trained for the job like the motor-car drivers. And while we still have left with us some of the reckless and irresponsible ones who are a menace to the road, by and large we move motor cars by the millions with amazing skill and safety, and so we do our business. The horses remaining take no notice of them, and David today, were he living, could ride down the road in Van Hornesville with safety, without irritation, without bitterness or even envy, because the chances are even if he kept his horse, he would have a motor in the barn standing beside it. So our big business has not justified the fears of our people. Exploiters no longer own the big concerns. Bankers no longer own them; their shares, like motor cars, are spread from one end of the country to the other in every city and village of the United States. And broadly speaking, the vast organizations are in skilled hands and the road is reasonably safe.

Now when we think of what is right or wrong in business, we must take account of the conditions under which such impressions are formed. Everything was wrong with business, or especially big business, in common opinion in 1905. Like motors, it appealed to the daring only. Such prejudices as exist against it today are much more largely due to the recollections of the old days than to real complaints of this day. Just as the horse driver today is less considerate and less careful on the highway, so it is likely to be true that the smaller units of business, not the larger ones, are less considerate and less careful. We have had to go through this process of adjustment, however. We have had to change our rules and practices in business and our laws governing it in the last quarter of a century, just as we have had to change our rules and practices on the highways. We have had to extend governmental control over business by way of regulation in the interest of all, just as we have had to compel the carrying of lights and license plates on motor cars. We have had to broaden the road and strengthen our bridges in order to prevent collapse, and so in the matter of reserves and conservative business practices, our new concerns, for the most part, are far superior to the old. We have to see further ahead on the road and so we put strong headlights on our cars to show the road, just as we put research laboratories and long-time budgets and surveys on to our machines of business.

Now I am not here to say that all is right with business. It is far from that. But I am here to say that in the last quarter of a century, we have made great progress toward the right. Our difficulty does not come so much from bad men or bad principles as it does from the difficulty of applying right principles to increasingly complicated situations. True, we have still an occasional drunken driver, an occasional malicious driver, an occasional ignorant driver, but they are not our principal danger. Our greatest risk is in the mistaken judgment of good drivers or their inexperience or carelessness where the traffic is heavy and the signals are complicated.

Let us take an example or two. What is right or wrong with the discount rate of the Federal Reserve Bank of New York, or with the bank rate, as they say in London when it is fixed by the Bank of England? Do you say there is no question of right or wrong in the moral sense of the bank rate—that is a financial matter? And yet I am here to tell you that I know of no act in business which bristles more with moral problems than the fixing of a bank rate. I do not mean problems in the sense that the men who fix that rate are likely to act in bad faith. Not at all. I mean in the sense that men may fail to apply correctly the sound moral principles which they recognize to a difficult and complicated business problem. Sometimes later when the thing has been done, and looking backward it is found that a mistake was made, then it seems so clear what should have been done that men without experience or with little experience, or men who are looking for trouble, say: "Something is wrong with business—look how that bank rate was fixed."

Now the making of a bank rate affects the volume of currency and credit. It increases or diminishes the value of money. As a result of it a debtor pays more and a creditor receives less, or else the converse is true. Every wage earner is affected in the purchasing power of his earnings by the bank rate. Every aged person or invalid dependent upon the income of a trust fund may have more or less of the things he needs as a result of the bank rate. It is a high moral responsibility to fix a bank rate.

When I was in Germany in February of 1924 working on the Dawes Plan, you will remember that the currency of Germany was depreciating so rapidly that the industries paid their wages daily, and sometimes indeed twice a day. Standing with the lines of employees was another line of wives and mothers waiting for the marks. The wife grabbed the paper from her husband's hand and rushed to the nearest provision store to spend it quickly before the rapid depreciation had cut its purchasing power in two. When the representatives of labor in Germany appeared before the Dawes Committee, I put to them this question: "What can this committee do for German labor?" I expected the answer to be some one of the slogans of labor, such as the eight-hour day, old-age or disability pensions, insurance against unemployment, or something of that kind. Much to my surprise the answer came promptly: "What your committee must do for German labor is to give us a stable currency." "Do you know," the representatives of German labor said, "that for many months it has been impossible for a wage earner in Germany to perform any of his moral obligations?" Knowing that a child was coming to the family at a certain time, there was no way by which the husband, through effort or sacrifice or savings, could guarantee his wife a doctor and a nurse when that event arrived. One knowing that his mother was stricken with a fatal disease could not by any extra effort or sacrifice or saving be in a position to insure her a decent burial on her death. And so he said: "Your committee must, just as a basic human thing, give us a stable currency and thereby insure to the worker that his wages will have the same purchasing power when he wants to spend them as they had when he earned them." Ladies and gentlemen, prior to that I had always thought of money and currency and credit as a mechanism of finance, impersonal in its operation. Not until then had I appreciated how closely it lies to life and the basic moral problems of every man and woman. Yes, indeed here the traffic is heavy and the signals complicated.

Now why have I taken all this time to speak of a very remote and highly technical question such as the fixing of the bank rate? Why have I endeavored to suggest to you that moral questions are involved in that particular action? It is only for this: I want you to get in your mind now, once and for all, that when you discuss what is right in business the difficulty lies not in determining what is right in principle. It is rather in the application of the principle to the vast, complex problems of our modern business. If you ask me with reference to business what is right in principle, I answer that the golden rule supplies all that a man of business needs; yet if you ask me to apply the golden rule to a bank rate, I find it amazingly difficult to do. It is like telling me to apply the multiplication table to the design and manufacture of a steam turbine. I know the principles of mathematics underlie the building of that great machine, but it is a highly difficult problem to step from the multiplication table to the steam turbine. If by any chance that turbine is not built in accordance with mathematics it will explode, lives will be lost, and ruin come to many innocent people. And so the design of a turbine requires conscience and care in the engineer and the highest regard for moral values at every step in order that the machine intended for service and value to man may not turn out an instrument of menace and destruction.

To return, however, to the point. What is right in business requires, in highly complicated situations, that the golden rule be applied by men of great understanding and knowledge, as well as conscience. They must be technicians in the sense of making the connecting link between the golden rule on the one side and the most complicated business transaction on the other. They must be as highly skilled as the turbine engineer who makes the connection between the multiplication table and the modern high-pressure turbine with its high temperature, wheels revolving at great speed, and an electrical output which if let loose is as destructive as the lightning of the gods.

Now, I purposely omit from this discussion the immoral things which may be done in business by weak and dishonorable men. True it is that there are occasional defalcations. There are here and there plain breaches of trust. There is the usual wreckage of dishonesty in different forms appearing now and then in business. Whenever it occurs, it is exploited in the headlines of the newspapers, not because it is the common, but because it is the unusual thing. The percentage of plainly dishonest things in business is very small compared with the vast total of the operations going on. There is no more need for me to discuss these cases under the title of "What is Right or Wrong in Business" than there would be for me to review the cases in our state prisons or in our lunatic asylums in order to determine what was right or wrong in society. By and large, business visits very quickly its own penalties on the dishonest man.

Having suggested to you that it is not the crook in modern business whom we fear, but the honest man who does not know, I wish to review briefly some of the advances which we have made during the last thirty years, in which I have been fairly intimate with the activities of business. I may say that during that time the moral standards of business have been advanced. A certain amount of astuteness and cleverness and sharpness of the eariler day has disappeared. They would not work very well in large business. A storekeeper may short-measure or short-weight his customer and make a little by that method. He may even induce his clerk to short-weigh or short-measure, but he can not organize a vast department store on that basis. Either his employees are honest people who would refuse to do it, or he would soon have as employees a vast organization of crooks who would beat each other and soon ruin the proprietor himself. Big business does not lend itself readily to dishonesty and crookedness. Great organizations of human beings can not be built on that theory. You can not teach an organization to steal from your customer and object very much if your cashier takes money out of the till. Honesty and uprightness must exist in great business organizations on the simple ground of expediency, if no other. And so as our business has grown large, I think we can say that moral standards have improved. It is safe for you to buy today under great trade-marks almost anything you wish without previously examining the package. You will find quantity, quality, and price right. It may be no moral tribute to the managers of business. It may be only the result of their intelligence, for they know that any other practice spells ruin. So here, certainly, simple honesty has its own rewards.

Then, too, there is another development of the last generation which I think has tended toward improvement in our standards. Again it results from the development of big business. Let me get at it this way: Who are the persons responsible for the right or wrong conduct of a business? Two generations ago you would have unhesitatingly said: "Why the owners, of course. They are the people responsible for it." Is that answer true today? Let us look and see. Who are the owners of these big businesses like the Telephone Company, or the Steel Corporation, or the General Electric Company, or the railroads? The law says the stockholders are the owners, and that is the theory. Well, there are some thousands, and frequently hundreds of thousands of them in a single corporation. Suppose you go to the school-teacher in Vermont who has a large share of her life savings invested in five shares of the General Electric Company and say to her: "Madam, you are an owner of the General Electric Company and I hold you responsible for the moral conduct of its business." What would her answer be? That she knew nothing about its business. The Company had always paid her dividends; her investment had been profitable; and she was assured that it was safe. She never thought of attending a stockholders' meeting, and would not know what to do if she did. Once a year she received a piece of paper called a proxy and did not understand particularly what it meant and so never bothered to sign it but threw it in the wastebasket. That is the way she, as owner, exercises her responsibility for the moral conduct of the business of the General Electric Company. And there are 50,000 of them exercising exactly that kind of control over the moral conduct of our business. Well, suppose you go to a large investor and say to him that he owns a very large block of shares in the General Electric Company and he is in a position to exercise great influence, and you hold him responsible for the moral conduct of its business. What will his answer be? He will say: "My bankers have advised me that it is a very sound business. We have held that stock in our family for many years. It has always paid us dividends and shown us increasing value in principal. I do not know anything about the business except that I look at the financial statements. I do not even know whether the stores at which I trade sell General Electric products. I never bothered to inquire. I do not even know that my household buys General Electric products. I never thought to look. Obviously, I assume no responsibility for the material welfare of that business, and certainly you can not expect me to be held responsibile for its moral conduct—in fact, I would not know, in those complicated transactions, whether a given policy was wise or not. Clouded as the issues are, I could not know whether a course of action was right or wrong." That would be your answer. The point is that in our modern business organizations of large size, we have completely divorced ownership from responsibility. Two generations ago ownership meant responsibility. Now ownership has little or no relationship to the conduct of the business. As a result of this, we have developed managers of business, chairmen and presidents and vast executive organizations. They alone know the business. They must be held responsible not only for its material welfare, but for its moral conduct.

When this separation of ownership and management on a large scale first took place some 25 or 30 years ago, the managers of business rather considered themselves as the paid attorneys of the stockholders to get results. The code then was that the manager must get results, honestly if he could, dishonestly if he must, but get results. He must not be too scrupulous about it, because if he did not want to do what was necessary to get results, others stood ready. So we had for a time a rather demoralized situation in big business. The vast power of the great organization was frequently used through coercion to get results. Great shippers forced railroads into secret rebates, unscrupulously overcame small competitors, and so through the exercise of power in one form or another accomplished unjustifiable results. Power especially when newly acquired always leads to excesses. Our early motor-car drivers were much more lawless than the present ones.

Then came a new idea in management. It is not yet full grown, but it is showing signs of rapid development and the greatest promise. I must say that I think the new idea sprang largely from the fact that lawyers were advanced to high management positions. This was initially done because our laws became so complex that for a time it was difficult for anyone except a lawyer to run a big business and keep within the law. While that was the reason for the lawyer coming into these positions, the result was quite different from that anticipated. If there is one thing that a lawyer is taught, it is knowledge of trusteeship and the sacredness of that position. Very soon we saw rising a notion that managers were no longer attorneys for stockholders; they were becoming trustees of an institution. Now that is a great change. If you will pardon me for being personal, it makes a great difference in my attitude toward my job as an executive officer of the General Electric Company whether I am a trustee of an institution or an attorney for the investor. If I am a trustee for the institution, who are the beneficiaries of the trust? To whom do I owe my obligation? My conception of it is this: That there are three groups of people who have an interest in that institution. One is the group of fifty odd thousand people who have put their capital in the General Electric Company, namely, its stockholders. Another is a group of well toward 100,000 people who are putting their labor and their lives into the business of the General Electric Company. The third group is composed of the customers and the general public.

Now as a trustee for these three groups, what would I most desire in the interest of all? First, that the credit of the institution should be so good that it could get its capital at the lowest rate even under the worst conditions. In other words, one would desire an option on capital supply. Failing in this, there would be no plant nor tools for labor. Workers would lose their jobs and customers would lose their product. In order to obtain an option on capital, it would be necessary to bulwark the institution adequately with reserves and thereby guarantee the safety of the capital and the continuity of its return. It would be necessary to have good relations with labor and a good market for the product, because that too is a guaranty of a continuous income to the investor. After one has the capital supply insured, he would wish a call on the labor supply. He would want his workers to feel that the institution was a good place to work and that the wages were as good or better than anywhere else; that men's rights to their jobs were respected, and that continuity of employment was at least better than in other plants. Given these things, the institution would have an option on its labor supply and might be expected to be free from labor difficulties. Third, one would want the product to be so good and the price for it so reasonable that buyers would prefer it to other products and so take it in slack times as well as good. In other words, one would want an option on the market. With these three options, one on capital, another on labor, and the third on the market at all times, the trustee could feel that the institution had reached its maximum safety for the three groups of which he was trustee. True it is, in addition the concern must meet its public obligations and perform its public duties—in a word, it must be a good citizen.

I think what is right in business is influenced very largely by the growing sense of trusteeship which I have described. One no longer feels the obligation to take from labor for the benefit of capital, nor to take from the public for the benefit of both, but rather to administer wisely and fairly in the interest of all.

And now I come back to my first point. It is no simple matter to determine right and wrong, even as between the groups which I have indicated. To protect capital one must build up reserves against bad years or unforeseen contingencies. To grant fair wages or high wages and adequately pay employees means adjusting the price so as to provide income adequate to do it. To try to increase a price for the sake of labor without regard to whether your labor is efficient, productive, and progressive, would be to take the road to ruin. It would be distinctly wrong. It would destroy continuity of employment, because one morning we would wake up and find our business gone; our price too high; a product not good enough; employees discharged. Just what is right in all cases we can not foresee even with the greatest effort. We make mistakes. We learn from our mistakes. We try to correct them in the future. Turbines will blow up, notwithstanding the multiplication table, occasionally when the engineers misapply the rules. Capital will get too much, or labor too little, or the public not enough occasionally, when the management misjudges the application of the golden rule to the complicated problems which we have. But by and large, looking over the quarter of a century with which I have been familiar, I am pleased with the rapid progress which we are making toward the right in business. We are not perfect and never shall be, but we are now training young men with a sense of these great responsibilities and we are providing them experience from our own mistakes. It is our one consolation for making them. As time goes on, I feel that the right in business will more and more prevail. The larger business becomes, the more scrupulously careful the administrators of it will be. We have had much difficulty with questions of technical competence and moral responsibility in the offices of aldermen, but we have had practically none in the great office of President of the United States. Somehow, as responsibility increases, men are found big enough to meet adequately the great questions of right and wrong which come to them. So I welcome big business and big responsibility, not in the fear that it will make business wrong, but in the hope and belief that it will make business right.

After I had written the foregoing statement out of my own experience, I happened to be examining last night a little manuscript of Emerson which I own, and there I found this statement written 100 years earlier, not out of his experience but out of his head:

> "The habit of directing large affairs generates a nobility of thought in every mind of average ability. For affairs themselves show the way in which they should be handled and a good head soon grows wise and does not govern too much."

And so with your permission, I will reverse the practice of Dr. Fosdick and leave you my text from Emerson last. You may preach your own sermon and then you will be pleased with it.

New Building Code for Southern and Western Cities

Thirty-eight municipalities have their names on the honor roll of the Pacific Coast Building Officials' Conference. These cities, now operating under the regulations laid down by the Uniform Building Code, have followed the lead of Sacramento and Alhambra which adopted that code late in 1927. They are as follows:

Sacramento, California
Alhambra, "
Fontana, "
Redlands, "
Oceanside, "
San Bernardino, "
Laguna Beach, "
Pomona, "
Fresno, "
Piedmont, "
San Rafael, "
Coronado "
El Monte, "
Ontario, "
San Jose, "
Visalia, "
Fullerton, "
San Francisco, "
Pittsburg, "
Claremont, California
Walnut Creek, "
Tulare, "
National City, "
San Fernando, "
Livermore, "
Berkeley, "
Martinez, "
Compton, "
Corcoran, "
Madera, "
Eugene, Oregon
Klamath Falls, Oregon
Shreveport, Louisiana
Monroe, "
Meridian, Mississippi
Eldorado, Arkansas
Prescott, Arizona
Tucson, "

Thus in the building code of each of these localities, there is now a section covering the electric welding of buildings. According to this provision it is now legal for the Commissioner of Buildings in each place to grant, in the same manner as for riveted frames, permits for the erection of electrically welded steel building frames also.

Section 2710 of the Uniform Building Code authorizes the use of welding and sets forth the essential elements needed by engineers and architects in working out the designs for welded joints in steel beams and columns used in building construction.

The Pacific Coast Building Conference is an organization whose members are the building inspectors and commissioners of buildings, banded together to secure the adoption of a uniform building code. As a result, engineers and architects who design buildings, and contractors who build them, may have but one type of code to conform to instead of a different code in each place.

In addition to the list of names given, there are many cities in which the code is either now being adopted or the ordinances of adoption are being prepared. In the eastern section of this country, various organizations have been at work for some time on a building code incorporating a section covering welding.

Aircraft Compass Problems

The Earth's Field—Compass Errors—Types of Compasses—The Magneto Compass—Advantages of Magneto Type

By T. R. RHEA

Marine and Aircraft Engineering Department, General Electric Company

There is something strangely fascinating about the ability of creatures to make journeys to unseen destinations without the aid of recognized landmarks. In doing so, mankind has sought and found a means whereby this may be accomplished; but the perfectibility of the method still engages attention. The elements treated in this article were presented at a recent meeting of the Kansas Engineering Society.—EDITOR

A MAN who contemplates the design of a compass usually has several grievances against nature. He complains that nature hasn't coöperated; that she has not made the earth's field strong enough. A field of roughly half a gauss is the most the designer can expect and even that has a direction almost perpendicular to the earth. The component horizontal to the earth's surface is the only component that has a directive sense. The vertical component seems simply to be thrown in for good measure and to annoy the user of the compass.

Furthermore, the direction of the magnetic north is a good deal different from the true north. From Seattle (Wash.) one looks some 25 deg. to the east of true north to look directly toward the magnetic pole. From Maine one must look nearly 25 deg. to the west of true north. This gives a change of about 50 deg. within the United States. Hence the aviator is forced to carry a small map showing the magnetic declination. Fig. 1 shows a typical correction card, giving the magnetic declinations for the United States.

When flying in the state of Washington, for example, the aviator must subtract 25 deg. from his compass reading to get the true north, provided no other compass errors exist. When flying in Maine the aviator must add 25 deg. to his compass reading.

Errors Applying to Magnetic Compasses

A list of the factors giving rise to the errors to which any type of magnetic compass is subjected is included at this point, since it will at once present the nature of the problems with which the compass designer must contend. These errors will be explained later. Declination will not be listed as an error.

(1). Ship's magnetized iron
(2). Ship's unmagnetized iron
    (*a*). Unsymmetrical in azimuth
    (*b*). Unsymmetrical in vertical plane
(3). Acceleration errors due to compass card being suspended as a pendulum.

On aircraft it is practical to provide compensation for only those errors due to ship's magnetized iron. The acceleration errors are always present, but their after effects can be minimized by intelligent distribution of the card mass and fluid damping.

The Magnetic Card Compass

The origin of the magnetic card compass is lost in antiquity. The name and nationality of its inventor is not known. It is a tremendously useful device, however, despite the fact that the earth's field is not all one could wish for.

The magnetic compass usually consists of a card upon which are marked the points of the compass. Below this card are suspended two or more parallel magnets. In aircraft compasses usually two are used, as this affords a symmetrical distribution of mass about the pivot point. The card and magnets are supported on a small cup jewel by means of a needle point. The weight is so distributed that the center of gravity is considerably below the point of support. If the compass card is to lie horizontally, the mass must be shifted slightly to one side to correct the tendency of the vertical component of the earth's field acting on the magnets to tilt the card.

Suppose with such a compass mounted in an airplane the pilot sets out to fly a due-northerly course, and further that he is "flying blind" in a dense fog.

If he turns to the right, perhaps unknowingly, his compass lies glibly and informs him he is turning to the left. This peculiarity is common to all magnetic compasses whether of the earth inductor type or not. The explanation of this is to be found from a consideration of the vertical component of the earth's field and the pendulum action of the card. When the plane banks and turns to the right the pendulum follows the resultant force of gravity and acceleration. The compass magnets being no longer in the horizontal plane are acted upon by the vertical component of earth's magnetic field, which is approximately three times as strong as the horizontal component. This component of earth's field turns the compass card in the same direction as that which the airplane is turning. That is, if the pilot turns west his compass would inform him he is turning east, thus causing him to turn further in the wrong direction to correct his error. This is one of the reasons why the compass is useless as a turn indicator.

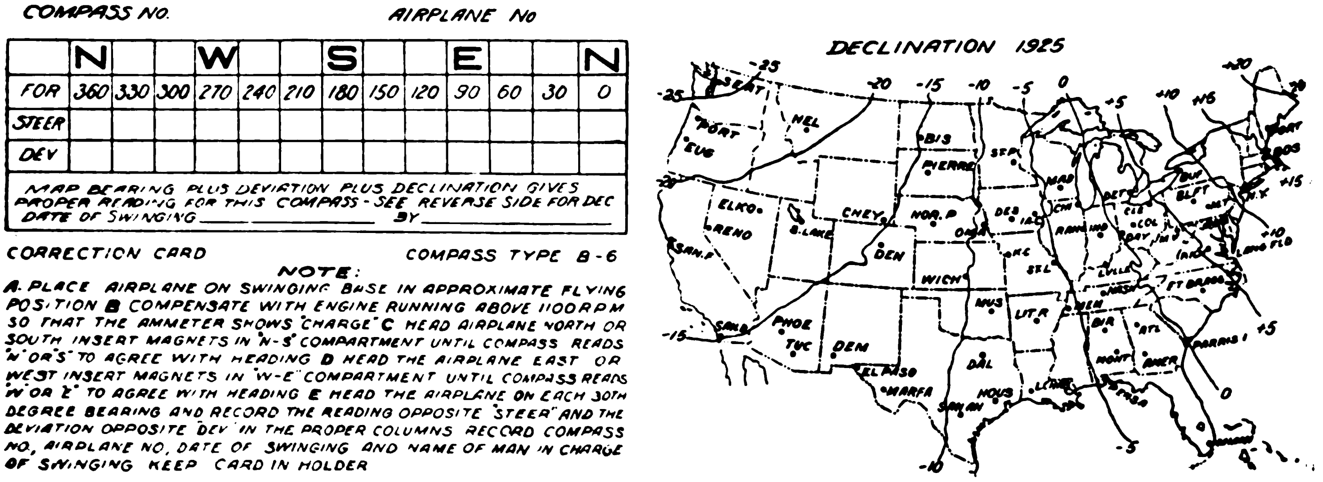
This acceleration error may be simply demonstrated as follows: upon a sheet of paper draw a line representing the magnet and point it north. Represent the vertical component of the earth's field by a pencil perpendicular to paper. Go into a bank, *i.e.*, tilt the paper athwart ship. The pencil, representing the earth's vertical component, will then have a component in the plane of the paper. This component in the plane of the paper acts on the compass magnets giving the false reading. This error does not appear on the south course. The foregoing consideration applies only to the northern magnetic hemisphere.

In the aircraft compass the bowl is made spherical and filled with kerosene to provide damping of oscillations. If the bowl is made other than spherical, the rolling and pitching of the plane disturbs the liquid and the liquid disturbs the card.

The indicator is a sensitive micro-ammeter with its zero position midway on its scale.

The rotor must be pendulously supported to keep its axis vertical so as to cut only the horizontal component of flux. In this way it is subject to exactly the same acceleration errors as the card compass. The rotor is driven through a universal joint.

To set a course the brushes are rotated to such a position with respect to the earth's magnetic field that the voltages generated in the various coils adds up to zero. As long as this course is maintained the indicator remains on zero. If the pilot deviates from the course to the right the indicator has (arbitrarily) a positive current through it due to the new position of the brushes with respect to the earth's field. If the deviation from the course is to the left, the current is (arbitrarily) negative and the indicator so records.



COMPASS NO. AIRPLANE NO

	N			W			S			E			N
FOR	360	330	300	270	240	210	180	150	120	90	60	30	0
STEER													
DEV													

MAP BEARING PLUS DEVIATION PLUS DECLINATION GIVES PROPER READING FOR THIS COMPASS - SEE REVERSE SIDE FOR DEC

DATE OF SWINGING ______ BY ______

CORRECTION CARD COMPASS TYPE B-6

NOTE:

A. PLACE AIRPLANE ON SWINGING BASE IN APPROXIMATE FLYING POSITION B COMPENSATE WITH ENGINE RUNNING ABOVE 1100 RPM SO THAT THE AMMETER SHOWS "CHARGE" C HEAD AIRPLANE NORTH OR SOUTH INSERT MAGNETS IN "N-S" COMPARTMENT UNTIL COMPASS READS "N" OR "S" TO AGREE WITH HEADING D HEAD THE AIRPLANE EAST OR WEST INSERT MAGNETS IN "W-E" COMPARTMENT UNTIL COMPASS READS "W" OR "E" TO AGREE WITH HEADING E HEAD THE AIRPLANE ON EACH 30TH DEGREE BEARING AND RECORD THE READING OPPOSITE "STEER" AND THE DEVIATION OPPOSITE "DEV" IN THE PROPER COLUMNS RECORD COMPASS NO, AIRPLANE NO, DATE OF SWINGING AND NAME OF MAN IN CHARGE OF SWINGING KEEP CARD IN HOLDER

Fig. 1. A Compass Correction Card, Showing Tabular Form for Calibrations and (on reverse) a Chart of Magnetic Declination for the United States

The ordinary card compass must be mounted somewhere within the easy vision of the pilot. This mounting is usually on the dashboard or cowl. This is probably the most unfavorable magnetic location on the plane, because the engine or other magnetic material is in the closest proximity to this location.

The best that can be done about these errors is to provide some compensating magnets attached to the compass. These magnets are adjustable in compensating effect both in magnitude and direction. They are adjusted to annul any magnetic field due to permanent magnetism of the plane but they cannot be used to correct for the distortion of the earth's field due to unsymmetrically located iron, such as the engine.

The Earth Inductor Compass

The need of some sort of remote indicating compass, which could be placed in a more favorable magnetic location, has given rise to the development of the earth inductor compass.

The earth inductor compass consists of a direct current armature, with brushes, in which the earth's horizontal component of field is utilized for excitation.

The brushes are set once and for all with respect to an azimuth ring graduated into points of the compass so that, when the indicator registers zero, a glance at the azimuth ring indicates the position of the brushes and the course. When the pilot wishes to change to a new course he simply turns the azimuth ring on his dashboard to the desired indicated course. Through a flexible cable drive this shifts the brushes with respect to the earth's field. To bring the indicator back to zero the brushes must be brought back to the same relative position with respect to the earth's field. This is done by changing the heading of the plane to the new course.

A criticism has been offered to the earth inductor compass because of the fact that there are two positions on the commutator where zero voltage is generated. The positions are 180 deg. apart. It might be supposed that if an aviator were flying absolutely "blind" he would not know from looking at the azimuth ring whether he were traveling in the indicated direction or 180 deg. in exactly the opposite direction, as his indicator reads zero in both instances.

However, if he is on the indicated course and not on the course 180 deg. from there, he has a very definite indication that such is the case. If he turns to the right the indicator moves to the right and vice versa. If, however, he is 180 deg. from the indicated course and turns to the right the indicator turns left. The explanation of this is quite simple to anyone familiar with d-c. generators. A 180 deg. shift of brushes could be effected simply by reversing the connection to them. For a deviation to the right of the plane the current flows through the indicator in the opposite direction, giving the reverse indication.

The two principal advantages of the earth inductor compass are that it may be located in a place free from the ship's local magnetic disturbances and that it is a very easy and satisfactory thing by means of which to steer. Keeping the little indicator pointer in the middle of the dial is much less wearisome than keeping the compass card on a bearing like 10 deg. south of west, for example.

The disadvantages of the earth inductor compass are:

(1). It requires a universal joint to transmit torque to the rotor. This universal joint must be well made if it is not to disturb the vertical position of the rotor.

(2). The amount of voltage generated is very small and commutation difficulties are encountered. Lubrication is resorted to to keep the commutator clean and to prevent excess wear on the commutator.

(3). It is a complicated and costly instrument, adding considerable weight to the aircraft.

(4). All the accelerational errors of the ordinary magnetic card compass are present; but from the nature of its mechanical arrangement it lends itself to better damping.

On the other hand, however, the advantages of the earth inductor compass are very real ones; and in order that these qualities might be the more effectively utilized, a way was sought to overcome some of its disadvantages.

The Magneto Compass

The compass which has proved to be the best so far proposed is the invention of Dr. J. D. Tear and is provisionally called the "magneto" compass. The scheme for this instrument makes use of a bar of special magnetic material of high permeability and low coercive force, *i.e.*, it does not retain magnetism.

Let us assume that the bar is stabilized in the horizontal plane. It is always necessary to exclude the vertical component in any type of magnetic compass. If the bar is perpendicular to the magnetic meridian—*i.e.*, if it is pointing east and west—the earth's field induces no flux in the bar along its length. If now it is deviated slightly from this east-and-west position a flux is induced along the length of the bar. The direction of this flux depends upon which way it is deviated.

How may this flux be detected? A coil might be wound around the bar and the flux alternately increased and decreased by means of alternately opening and closing an air gap in the bar, exactly as is done in some types of magnetos. Suppose that a section is cut out and that there is inserted in its place a small rotating section, the coil being wound on the small rotating piece. Probably a better picture of what is now suggested is to consider a small spool upon which is wound a coil of wire. This spins about a vertical axis—an axis fixed with respect to the ship. Such an arrangement is shown in Fig. 2.

The two bars are stabilized pendulously about the center of the rotor so that they may lie in a horizontal plane whether the rotor axis is exactly vertical or not.

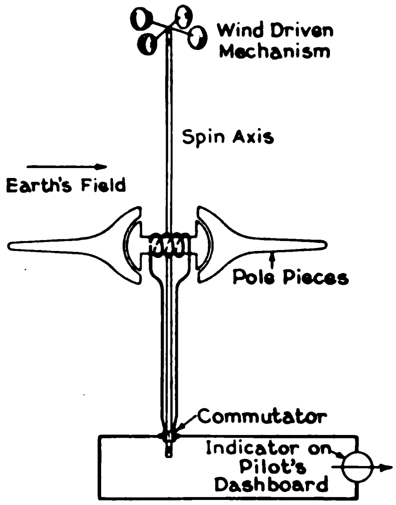


Fig. 2. Elementary Sketch of the Magneto Compass

The rotor is almost perfectly shielded from any outside flux by the flaring pole tips, except that which is led along the length of the bars or pole pieces. The spinning rotor cuts this flux and generates an e.m.f. in the coil. The e.m.f. is led to a very tiny two-bar commutator where it is rectified.

This scheme does not eliminate the commutator but it does eliminate commutator troubles because of its very small diameter and low peripheral speed. Also, the voltage to be commutated is several times as much as that of the conventional type. A trial run of three weeks, twenty-four hours a day, was made on the laboratory bench to determine if wear or high-resistance contacts developed at the commutator. No cleaning or oiling of commutator took place within this period, yet at the end of the run no wear was apparent on the commutator and no high-resistance contacts had developed.

The pole pieces of this compass are changed in azimuth instead of a shift being made in brush position. The brushes are so placed with respect to the pole pieces that when there is a maximum flux in the pole pieces maximum voltage is generated. The sensitivity (or amount of voltage generated) is not materially reduced when the brushes are shifted ten or twenty degrees from this maximum position. The accuracy of the course held is not affected at all by the brush position; only by the position of the pole pieces. In the conventional type of compass, the accuracy of indicating the course depends upon the position of the brushes. Wear of the brushes, which cover nearly twenty degrees of the commutator in the conventional type, would cause a quite serious error in the course indicated. Obviously this source of error is absent in the magneto type of compass, where the course indicated depends only on the relation of the pole pieces.

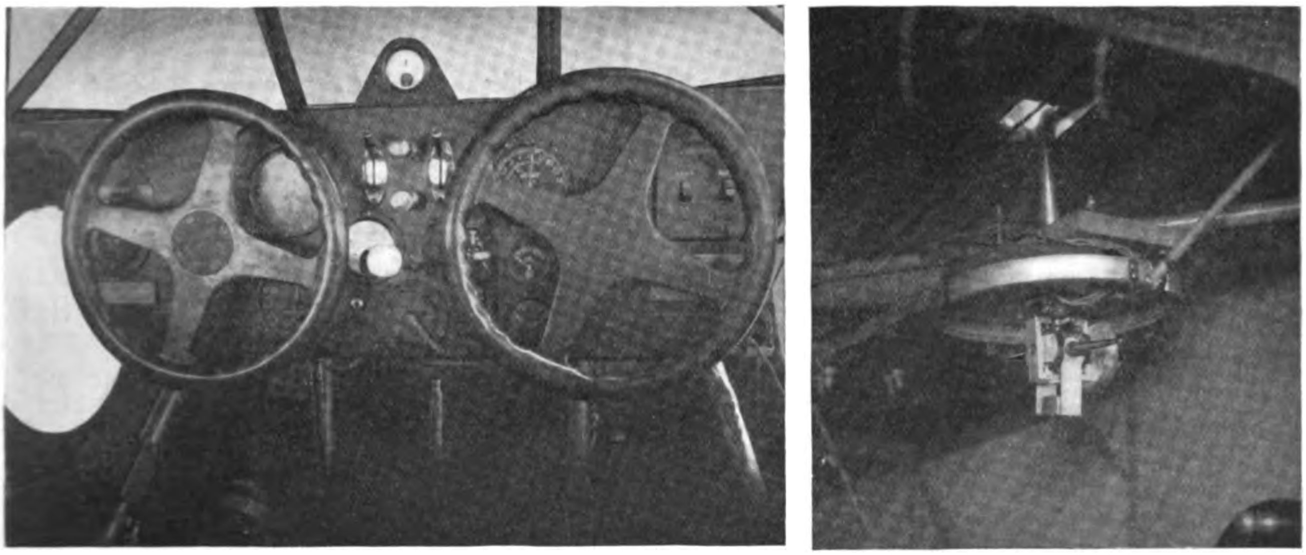
This type of compass then appears to have the following advantages:

(1). No universal joint.
(2). Stabilized part (pole pieces) does not rotate.
(3). Greater sensitivity (voltage) due to concentration of earth's flux by iron bar.
(4). Accuracy not impaired by brush position or brush wear.
(5). No commutation difficulties.
(6). No oiling or maintenance required because of small parts and very low commutator peripheral speed.
(7). Smaller and lighter than the present conventional type of earth inductor compass generator.

This type of compass has emerged from the laboratory and bench-test stage and is being tested in the air. So far, it has not developed any faults of a fundamental nature.

It has often been asked whether the remote indicating compass, such as the earth inductor compass, will replace the magnetic card compass. This, however, does not seem likely, since the magnetic card compass will probably always be used in a supplementary capacity. Its simplicity and comparative ruggedness make it essentially a very reliable device as a standby and check and for temporary and approximate alterations of course as, for instance, in flying around a storm; but the earth inductor compass is a truly fine navigational instrument and one by which it is very easy to fly.

The Magneto Compass Installed



In the left-hand illustration the indicator of the magneto compass is shown mounted at the top of the instrument panel of the airplane in which it was given its service tests. The right-hand illustration shows the magneto portion of the compass as mounted for service tests in the fuselage of the airplane. The projecting pole pieces, which determine the direction of the airplane with respect to the earth's field, are clearly shown. The magneto equipment is completed by a wind-driven impeller which is located at the top of the spin axis, but which is not shown here

Shaft Behavior at Critical Speed

Characteristic Behavior—Marked Reduction in Violence with Refined Balance—Reversal of Bending of Shaft—Graphic Theory—Stroboscopic Apparatus—Comparison of Theory with Tests—Shaft Deflection Formulas

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CRITICAL speeds of shafts have long been of interest to designing engineers, and there is a considerable literature on the subject. Many of the available references, however, deal solely with the calculation of the speeds of rotation which are supposed to be "critical"—*i.e.*, dangerous, and to be avoided—without describing the peculiar behavior which shafts are likely to exhibit at such speeds. The purpose of this article is to describe some of the phenomena of shaft behavior at critical speed, as observed in tests made with model rotors at the Schenectady Works of the General Electric Company.

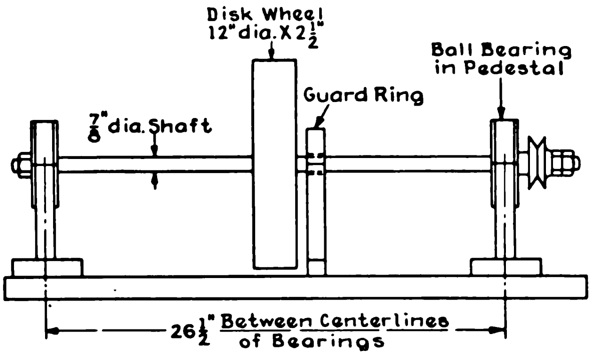
Disk Wheel
12" dia. X $2\frac{1}{2}$"
Ball Bearing in Pedestal
Guard Ring
$\frac{7}{8}$" dia. Shaft
$26\frac{1}{2}$" Between Centerlines of Bearings

Fig. 1. Small Model Rotor with Ball Bearings

Characteristic Behavior Shown by Small Model

The models used in these tests consisted each of a steel shaft running in two bearings, carrying a single disk wheel midway between them. Such a rotor, according to the older theory, should become *unstable* when running at critical speed, the stiffness of the shaft being completely neutralized by centrifugal forces, so that the slightest degree of unbalance would cause the shaft to deflect indefinitely (or "whirl") until it breaks, unless restrained. Tests with the model shown in Fig. 1 apparently confirmed this conception, for at a certain speed the shaft did vibrate alarmingly. Fig. 2 illustrates this behavior: the curve represents the amplitude of vibration registered by a dial indicator set to bear on the model shaft near the wheel. The 100-mil peak in the curve comes at the critical speed—about 1100 r.p.m. It is worth noting that the model quieted down above critical speed and ran very smoothly; also, that the violent disturbance was confined to a relatively narrow range of speed.

Marked Reduction in Violence of Critical Speed Disturbance Obtained by Accurate Balancing

This ball-bearing model had a specially forged chrome-nickel steel shaft, and a short and very tight shrink fit between the wheel and the shaft; and it had been balanced very carefully before the data shown in Fig 2 were obtained. Previous experience with shafts of less high-grade material, and with ordinary wheel fits, had shown that the heavy vibration encountered at critical speed would bow the shaft and spoil the balance—this resulting in still more violent vibration each time the critical speed was approached, until it became impossible to get the model up through the critical speed at all. Further experience with the better shaft, however, showed that the balance could be refined until the vibration at critical speed almost *disappeared.* The degree of refinement required to achieve this condition will be indicated, as well as the method by which it was obtained.

The original balancing, preceding the observations represented in Fig. 2, was done at resonance at a very low speed, with the model mounted in a rigid "balancing frame" arranged to oscillate about a pivot near one end—the other end being supported by a spring. This method was quite delicate, and the resulting balance was recorded as true to within about ¼ gram at 5 inches radius—equivalent to an eccentricity of the whole 85-pound rotor of only 0.00003 inch. This really good balance was accidentally spoiled in the course of some further experiments, and re-balancing was necessary. In trying to save time, the writer did away with the balancing frame and used a somewhat simpler set-up, as shown in

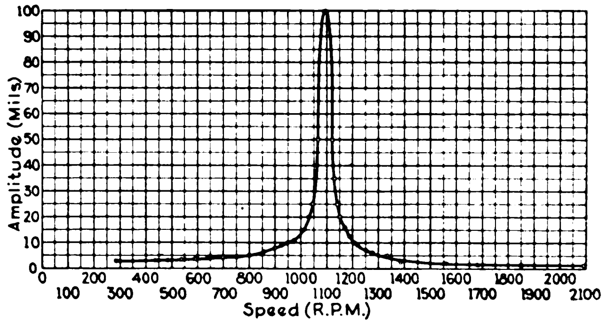

Fig. 2. Amplitude of Vibration of Model Shown in Fig. 1, Plotted Against Speed. Rotor balanced within ¼ gram at 5-in. radius, corresponding to an eccentricity of the center of gravity of the whole rotor of 0.00003 in.

Fig. 3. One self-aligning ball bearing was employed as a pivot at one end of the shaft, and the other was mounted in a special spring-supported housing. The oscillation resonance then occurred at about 450 r.p.m., and the amplitude was large but measurable with the dial indicator. Balance corrections applied by systematic trial and error reduced the amplitude to a small fraction of its initial value in a short time. The records indicate that the residual unbalance was then of the order of 0.000005 inch eccentricity, or about one-sixth of the value obtained with the balancing frame. The simpler set-up, therefore, not only saved time, but led to greater refinement of the balance.

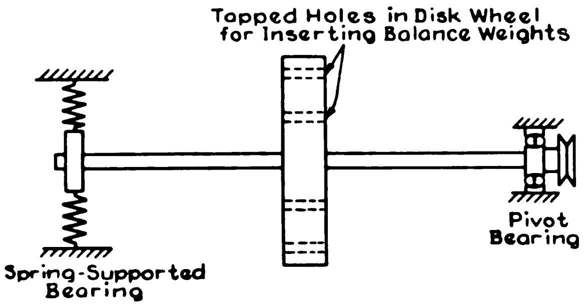

Fig. 3. Small Model Set up with Spring-supported Bearing for Balancing

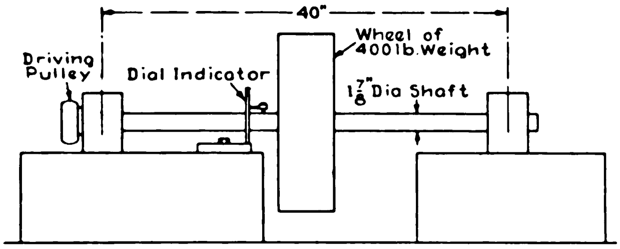

Fig. 4. Larger Model Equipped with Journal Bearings

The result was satisfactory beyond expectation, for when the model was returned to its original set-up, with both bearings rigidly supported, its peak amplitude at critical speed did not exceed 15 mils. It is interesting to note that this is roughly one-sixth of the original amplitude. The model would then run *continuously* at critical speed with the *same steady amplitude*, which was so small in comparison with its previous value as to be almost negligible.

Larger Model Balanced So That Critical Speed Could Not be Detected; Added Unbalance Causes Proportional Amplitude

The small model used in the foregoing tests was extremely sensitive to unbalance. A larger model with journal bearings (see Fig. 4) was found to be much less sensitive, so that similar refined balancing resulted in practically complete elimination of the vibration at critical speed. The proportions of this model were laid out to give a critical speed of about 1200 r.p.m., as calculated by the ordinary method; and this value was closely realized in test. The workmanship on this model was excellent; without having been balanced at all, it was run to critical speed and did not exceed 15 mils amplitude of vibration at the center of the shaft. The original good balance was refined by the method of trial and error, running in each trial to critical speed and observing amplitude. A few corrections sufficed to make the shaft as steady at the critical speed as at any other speed—the dial indicator showing a flutter of about ½ mil at all speeds. This adjustment was now made permanent. Additional temporary balance weights were added, however, to produce intentional unbalance; and these caused the model to vibrate again at critical speed. It was found that the maximum amplitude of vibration was very nearly proportional to the amount of weight added. See data plotted in Fig. 5. The violence of the disturbance at critical speed was roughly proportional to the degree of unbalance.

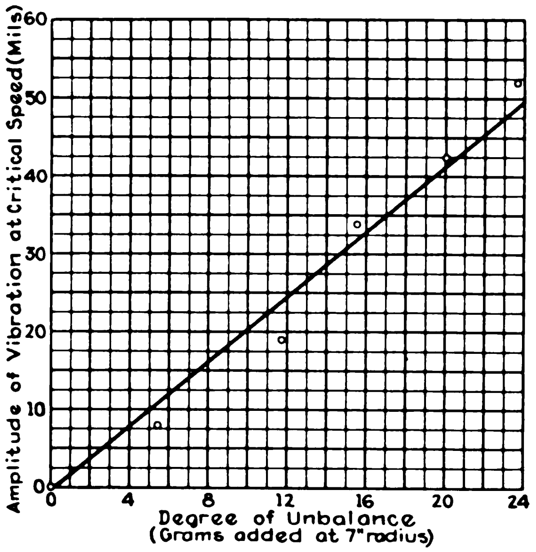

Fig. 5. Critical-speed Amplitudes Observed with Various Degrees of Added Unbalance

Journal Bearings Found to be a Source of Damping Resistance Limiting the Amplitude Reached at Critical Speed

The lubrication of this model had a marked effect on the amplitude reached at critical speed, and the proportionality between amplitude and unbalance held only for steady conditions of oil supply. With a fixed amount of unbalance, and constant oil flow through the bearings, the reading of the critical speed amplitude could be checked repeatedly within a few mils. But with considerably increased oil flow, the amplitude was reduced markedly; and with scant oil flow, the amplitude was increased.(1) In general, the greater the flow of oil through the bearings, the smaller the amplitude of vibration reached at critical speed. Some action in the bearings, therefore, depending on the lubrication, tended to limit the amount of vibration produced by the unbalance.

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(1)Also, with scant oil, the vibration on acceleration frequently carried over to reach its maximum at considerably higher speed, as will be illustrated in Fig. 11.

Theoretical Reversal of Bending of Shaft in Passing Through Critical Speed Confirmed by Marking Shaft

The peculiar reversal of direction of the bending of a shaft in passing through critical speed was investigated with the same model. The accepted theory of shaft behavior indicated that below critical speed the deflection of the shaft is radially outward toward the heavy, or unbalanced, side of the rotor. That is, the shaft bows out, yielding to the centrifugal pull of the unbalance, and whirls around so that a mark made by holding a pencil against the shaft will correspond in position to the heavy side—a condition briefly described by the phrase "heavy side running out." Above critical speed, the theory holds that conditions are reversed, the "light side running out."

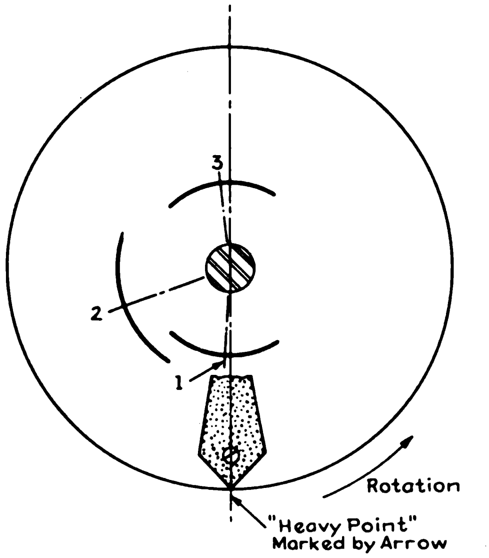

Fig. 6. Diagram Showing Position of Marks Made on Shaft of Model Relative to Heavy Point at Various Speeds

(1). About 20 per cent below critical speed.
(2). Very near critical speed.
(3). About 20 per cent above critical speed.

The model was thrown out of balance by the addition of sufficient weight at one point to cause a fairly large amplitude of vibration at critical speed—about 65 mils. This heavy point was marked by painting a white radial arrow on the wheel. The shaft was also painted lightly with chalk near its midpoint, and marks made on it with a weighted pencil while the model was running at several speeds, below, near, and above the critical speed. The results of this test are shown in Fig. 6. It is seen that the deflection at a speed well below critical was almost exactly in line with the heavy point on the wheel; while well above critical speed it was about opposite—confirming the theory. Further, near critical speed, the deflection was almost ninety degrees behind the heavy point. Other marks made at intermediate speeds—not shown in the figure—came at intermediate positions. This showed that in passing through critical speed there is a gradual transition of the direction of the bending, the *deflection lagging the unbalance* by an angle which varies from almost zero at well below critical speed, through ninety degrees at about critical, to almost one hundred-eighty degrees at a speed well above the critical speed.

Theoretical Shaft Behavior Expressed by Curves for Amplitude and "Angle of Lag"

Good qualitative agreement between theoretical and actual shaft behavior having been obtained, a more quantitative comparison was undertaken. In this connection, reference was made to a paper by H. H. Jeffcott, on "Lateral Vibrations of Loaded Shafts in the Neighborhood of a Whirling Speed," published in the *Philosophical Magazine* for March, 1919. He derives expressions for the amplitude of vibration, and the "angle of lag" of the deflection behind the heavy point, for a simple two-bearing rotor, in terms of the shaft stiffness, the weight or mass of the wheel, the amount of unbalance or eccentricity, a certain damping constant, and the speed—five variables, altogether. The writer found these expressions somewhat laborious to use in making computations of deflections and angles of lag for comparison with observed values. Simple transformations were worked out, however, which yielded equivalent expressions involving only three variables which were somewhat easier to use. (See derivation in the Appendix.)

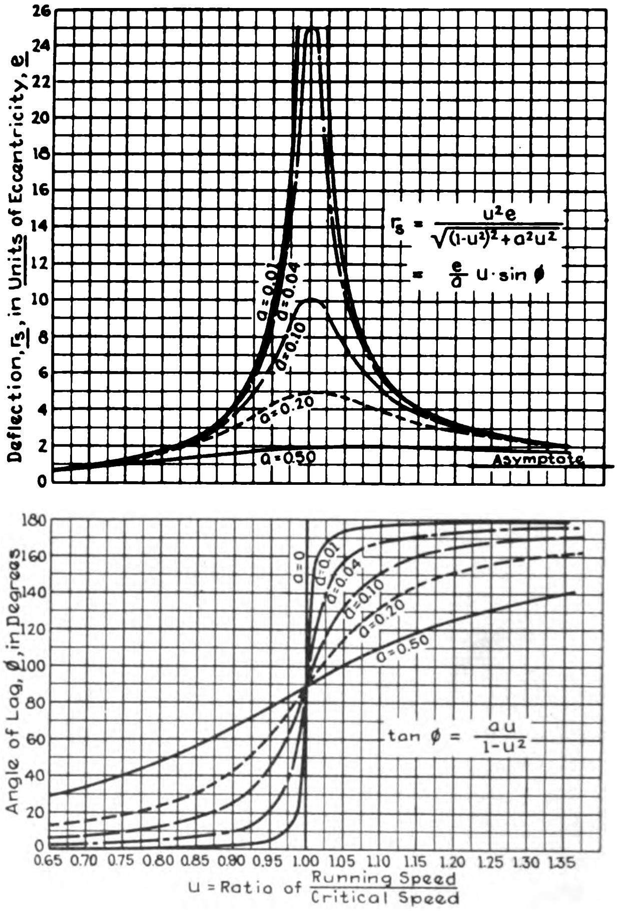

Fig. 7. Curves Representing Theoretical Expressions for Shaft Deflections and Angles of Lag Near Critical Speed

These equivalent expressions are also adapted to graphical representation, as in Fig. 7. The two families of curves show theoretical deflection (half amplitude) and angle of lag, plotted against *u*, the ratio of running speed to critical speed. The deflection is given in *units* of the eccentricity—being always proportional to the amount of unbalance. The angle of lag is given directly in degrees. Both of these quantities depend further on the degree of damping, represented by the damping constant, *a*, the curves being drawn for a wide range in its value. The physical significance of this damping constant is of interest. Its value is equal very nearly to the eccentricity divided by the maximum deflection reached at critical speed. For instance, if the maximum is twenty times the eccentricity, the value of *a* is 0.05. This relation facilitates comparison of the theory with the test results, since the theoretical curves can be drawn readily by interpolating in Fig. 7 for the appropriate value of *a*.

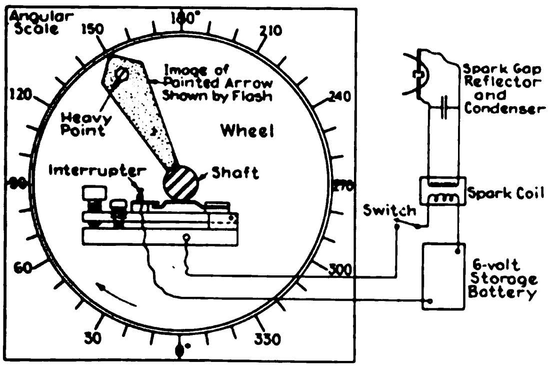

Fig. 8. Stroboscopic Apparatus for Measuring the Angle of Lag

Stroboscopic Apparatus for Measuring Angle of Lag

Measurements of the amplitude of vibration were made, as in the previous tests, with a dial indicator bearing on the shaft near its midpoint. But measurements of the angle of lag by marking the shaft, while well suited to the preliminary experiment, were thought neither convenient nor accurate enough for the more detailed observations. Special stroboscopic apparatus was therefore designed, by means of which direct readings of the angle of lag were obtained with the model running. This arrangement is sketched in Fig. 8. It consisted of a spark coil and a suitable discharge gap and reflector, together with an adjustable interrupter in the primary circuit set near the middle of the shaft in such a way as to be operated by the *vibrations*—not revolutions—of the shaft. A flash was thus produced each time the shaft approached the interrupter and broke the circuit. Since at constant speed the vibrations were synchronous with the revolutions, a stationary stroboscopic image of the model could be seen by the light of the flashes. In use, the interrupter was adjusted for each reading so that the shaft would just barely break the circuit, each flash therefore being timed at the instant of maximum deflection in the direction of the interrupter. With this adjustment, which was found to be quite delicate, the image of the arrow marking the position of the heavy point on the rotating wheel always appeared ahead of the interrupter position, in the direction of rotation. That is, the deflection lagged behind the unbalance. An angular scale graduated in ten-degree intervals was set up around the wheel, with the zero mark in line with the interrupter position. The stroboscopic image of the arrow thus gave a direct reading of the angle of lag.

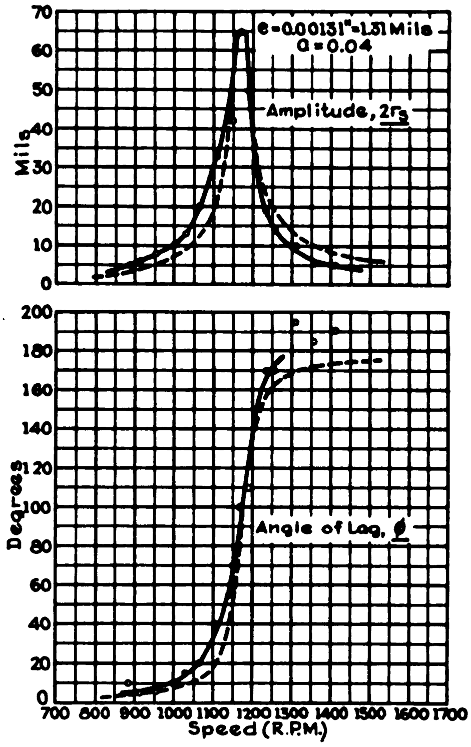

Fig. 9. Comparison of Theoretical (Dotted Curves) with Observed (Full Curves) Shaft Behavior; Normal Lubrication, Moderate Unbalance

Comparison of Theoretical Curves with Test Observations

Figs. 9, 10, and 11 show observed and calculated values of amplitude and angle of lag in the critical speed range, for various conditions. The full-line curves in each case are drawn through the test points; and the dotted curves, taken from Fig. 7, represent the theoretical conditions.

The observations plotted in Fig. 9 were made under normal conditions of lubrication and with a moderate amount of unbalance, corresponding to an eccentricity of the whole 400-pound wheel of 0.00131 inch. The maximum amplitude of 0.065 inch was reached at a speed of 1170 r.p.m.—the critical speed. The maximum deflection, or half-amplitude, being 0.0325 inch, the value of the damping constant, *a*, was very closely 0.00131/0.0325, or approximately 0.040. The theoretical curves for this value of *a* were obtained from Fig. 7 as follows: the speed ratio *u* for each point was multiplied by the observed critical speed, 1170; the ordinates of the deflection curve were multiplied by the known value of the eccentricity and doubled to give full amplitude; and the angle of lag was read off directly. The peaks of the two deflection curves were thus superposed at the outset, and the comparison is purely between their shapes. They are seen to agree fairly well, though there are some consistent differences.

Fig. 10 gives a similar comparison for 50 per cent greater unbalance (0.00197 inch eccentricity); but with greatly increased oil flow through the bearings the net result being a *reduction* of the maximum amplitude to 0.040 inch. Here the value of a is 0.0985. Again the agreement is good, though imperfect—the differences being of the same character as in Fig. 9. The third comparison, shown in Fig. 11, shows the same differences considerably exaggerated. The unbalance in this case is the same as for Fig. 10 (0.00179 inch eccentricity), but the oil flow through the bearings had been reduced. The amplitude reached a maximum of 0.110 inch at 1315 r.p.m., the value of a therefore being 0.0358.

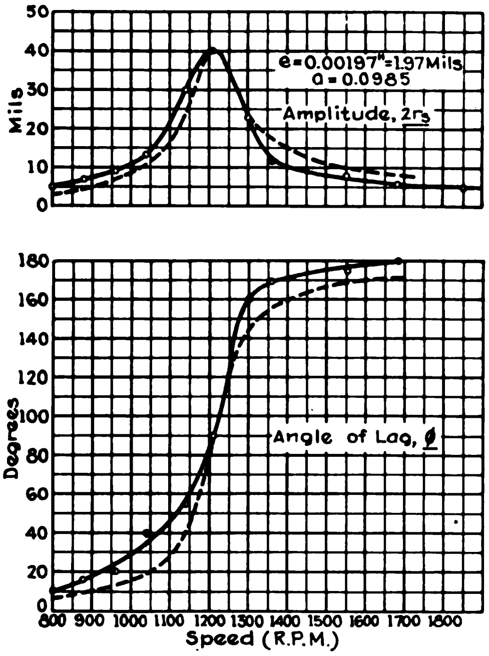

Fig. 10. Comparison of Theoretical with Observed Shaft Behavior; Excessive Lubrication, Heavy Unbalance

The fact that the critical speed was raised quite appreciably in the last case gives a clue to a plausible reason for the differences in shape between the test curves and the theoretical curves. The obvious explanation for the rise in critical speed is a stiffening of the shaft—which would be produced by the restraining action of the sleeve bearings when the deflection became large. This would seem to account for the early building up of the vibrations, as though for the normal lower critical speed of the unrestrained shaft. As the amplitude reaches a value, however, such that the shaft gains extra stiffness from the bearings, the vibration naturally carries over to reach a maximum at a higher speed. Having passed this maximum, the amplitude decreases, the extra stiffness is lost, and the shaft quiets down rather suddenly. In short, the use of rigid sleeve bearings in these tests appears to have imposed a condition not allowed for by the theory, that of variable shaft stiffness depending on the amount of deflection. The agreement obtained, however, seems close enough to indicate that this extra condition is not of much importance, and that the simple theory is satisfactory for rotors of this type which are reasonably well-balanced.

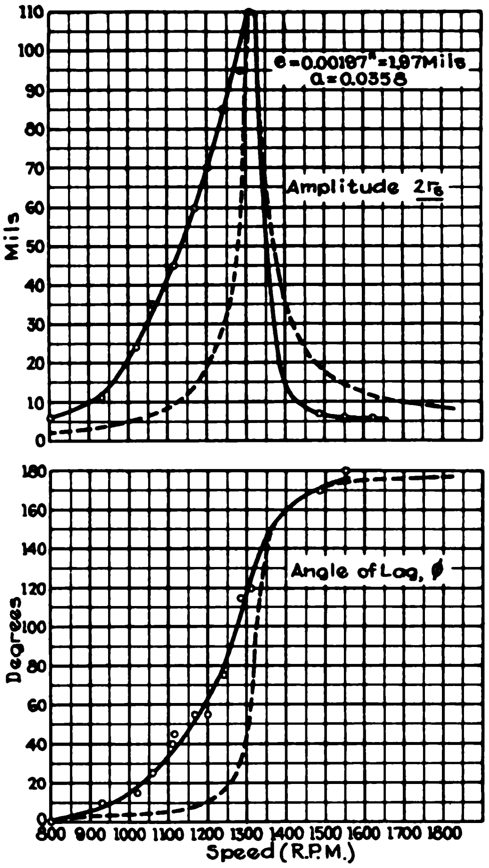

Fig. 11. Comparison of Theoretical with Observed Shaft Behavior; Scant Lubrication, Heavy Unbalance

Summary

The characteristics of shaft behavior brought out by this series of tests may be summarized briefly as follows:

(1). The "*instability*" which used to be considered an explanation for the vibration of a shaft at critical speed seems to be simply a matter of *unbalance*, since accurately balanced models ran smoothly at the critical speed, as also at all other speeds.

(2). The *amplitude* of vibration at critical speed was found to be roughly *proportional to* the amount of *unbalance*, or eccentricity; hence, in balancing operations, the amplitude at critical speed may be used as a sensitive measure of the amount of correction weight required.

(3). Different rotors vary greatly as to *sensitivity* to unbalance, much depending on the bearings. Thus.

a model running on self-aligning ball bearings was much more sensitive to slight unbalance than was another equipped with journal bearings; and, in the latter case, the sensitivity decreased sharply with increase of oil flow through the bearings, the degree of damping, therefore, depending directly on the oil flow.

(4). The phenomenon of the "*heavy side running out*" below critical speed, and the light side out above critical speed, was illustrated by marking the shaft of a model; and it was found further that the transition from one condition to the other was gradual, the deflection lagging behind the heavy point by about ninety degrees at the critical speed.

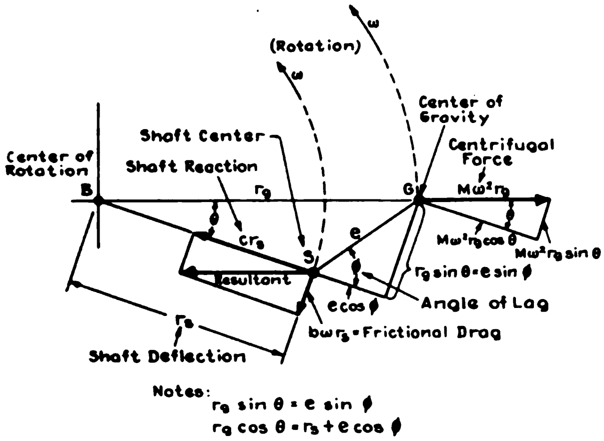

Fig. 12. Diagram of Forces for Derivation of Expressions for Shaft Deflection and Angle of Lag

(5). Curves representing observed amplitude, and also the "angle of lag" as measured with special stroboscopic apparatus, checked reasonably well with *theoretical curves* based on the simple expressions represented graphically in Fig. 7, which may readily be derived, as will follow in the Appendix.

The writer gratefully makes acknowledgment to Dr. Burt L. Newkirk, of the Research Laboratory, with whom he was associated at the time of performing these experiments, for helpful advice in connection with them, and for constructive criticism of this article.

APPENDIX

Formulas for the shaft deflection and angle of lag for simple two-bearing rotors are as follows:

$$r_s = \frac{M\omega^2 e}{\sqrt{(c - M\omega^2)^2 + b^2\omega^2}} = \frac{M\omega e}{b} \sin\phi \qquad (1)$$

$$\tan\phi = b\omega/(c - M\omega^2) \qquad (2)$$

where

r_s = shaft deflection (half amplitude) at speed ω, in feet.

ϕ = angle of lag of deflection behind the heavy point.

M = mass of wheel, *i.e.*, weight in pounds/32.2, assumed to be very large in comparison with mass of shaft.

ω = speed of rotation in radians per second, 2π (r.p.m.)/60.

e = effective eccentricity of whole mass due to residual unbalance; *i.e.*, the radius of the circular path of the center of gravity at very low speed.

c = stiffness constant of shaft, expressed in pounds load per foot of deflection, measured at the wheel.

b = damping constant, pounds frictional resistance effective at the wheel center, when that point moves (in vibration) at a velocity of one foot per second; total resistance being assumed proportional to the velocity of that point.

Other symbols to be used are:

$\omega_c = \sqrt{\frac{c}{M}}$ = critical speed, in radians per second.

$r_{sc} = \frac{M\omega_c e}{b}$ = value of r_s when $\omega = \omega_c$, which is very closely the maximum or peak deflection, at critical speed.

$u = \frac{\omega}{\omega_c} = \frac{\omega}{\sqrt{\frac{c}{M}}}$ = ratio of running speed to critical speed.

$a = \frac{e.}{r_{sc}} = \frac{b}{M\omega_c} = \frac{b}{\sqrt{cM}}$ = ratio of eccentricity to maximum deflection.

Equations (1) and (2) correspond, except for notation, to the expressions derived by Jeffcott (*loc. cit.*) in a somewhat lengthy treatment based on general differential equations of motion. They may also be derived directly from a diagram of forces, with the assumption of steady motion, as will follow.

Derivation of Formulas

Referring to Fig. 12, which is drawn in the plane of the wheel on the shaft, the point B is the center of rotation—*i.e.*, the position of the shaft center S when at rest. The point G is the center of gravity, at a distance e from S, e being the "eccentricity." The centrifugal force ($M\omega^2 r_g$) due to the rotation of the center of gravity about the point B, bends the shaft. This bending is resisted by the shaft reaction (cr_s) assumed to be proportional to the deflection. Rotation of the bent shaft meets with frictional resistance or "drag," ($b\omega r_s$) assumed proportional and opposite to the velocity of the point S. (This frictional resistance is largely in the bearings, but is assumed to be effective at the wheel.) The effect of this frictional drag is to make the deflection lag behind the centrifugal force by the angle ϕ, measured at the shaft center S, somewhat as is indicated in the figure. The centrifugal force forms a couple with the resultant of the shaft reaction and the frictional drag. This couple exerts a backward torque, which is counterbalanced by the driving torque—not indicated in the figure—which is assumed to be just sufficient to maintain constant speed. Equilibrium in steady circular motion requires the following relations to hold:

$$b\omega r_s = M\omega^2 r_g \sin\theta = M\omega^2 e \sin\phi \tag{3}$$

and

$$c r_s = M\omega^2 r_g \cos\theta = M\omega^2 (r_s + e\cos\phi) \tag{4}$$

or

$$(c - M\omega^2)\, r_s = M\omega^2\, e \cos\phi \tag{4a}$$

From Equation (3), directly

$$r_s = \frac{M\omega e}{b} \sin\phi,$$

or by squaring and adding (3) and (4a), we find

$$r_s = \frac{M\omega^2 e}{\sqrt{(c - M\omega^2)^2 + b^2\omega^2}}$$

which are the values given in Equation (1).

Now, dividing (3) by (4a),

$$\tan\phi = b\omega / (c - M\omega^2)$$

which is Equation (2).

Transformation of Formulas

The simpler expressions which were represented graphically in Fig. 7 were obtained by means of the following substitutions:

Let
$$\omega = u\omega_c = u\sqrt{\frac{c}{M}} \tag{5}$$

and
$$b = a\sqrt{cM} \tag{6}$$

so that Equations (1) and (2) become

$$r_s = \frac{u^2 e}{\sqrt{(1 - u^2)^2 + a^2 u^2}} = \frac{ue}{a} \sin\phi \tag{7}$$

and

$$\tan\phi = au/(1 - u^2) \tag{8}$$

The quantities u and a here replace M, ω, c, and b. Both u and a are ratios, pure numbers, and are easily evaluated from experimental data. The curves plotted in Fig. 7 used values of u as abscissas, and a as parameter. These curves are therefore general, applying to rotors of any weight, with shafts of any stiffness, with high or low critical speed, and with any degree of damping or unbalance. In fact, they are typical resonance curves, almost identical with others which could be applied to other mechanical or electrical problems, such as torsional oscillation of crank shafts, or current pulsation of synchronous motors directly connected to reciprocating compressors, etc.

Superchargers Standard on New Aircraft Engines

Especially designed superchargers are to be built into the three new types of aircraft engines which are the developments of the Wright Aëronautical Corporation in its test laboratories at Paterson (N. J.). This device is already standard with the larger-capacity engines manufactured by that company, with all engines manufactured by the Pratt and Whitney Aircraft Corporation, and with a new engine recently developed by the Curtiss Aëroplane and Motor Company. All of these engines are of the radial air-cooled type. By the use of this auxiliary to the engine increased efficiency is obtained in operation, including easier starting, greater reliability and better performance at high altitudes.

Superchargers have been used in increasing numbers on airplanes ever since the war. Beginning with military aircraft designed for high-altitude flights, applications have extended to all types. The practice in the past has largey been to modify standard engines to accommodate an external supercharger, but the rapid advance in research in the past few years has brought about the design of a supercharger which is now being adopted by all leading airplane manufacturers in this country for engines in sizes up to about 600 hp. This device is made an integral part of the engine. As a direct result of the use of these superchargers a new type of airplane engine was developed, utilizing air cooling, equipped with radial cylinders, and having a supercharger built in as an essential item of the engine construction.

The supercharger is primarily designed to improve the gasoline distribution and to give a small amount of supercharging when flying near sea level. In most cases, however, it is so arranged that it can be used to maintain sea-level power when flying at the usual altitudes. Thus, by maintaining conditions of greater pressure at the engine inlet, airplane engines can develop much higher power at any given altitude than was possible without the supercharger.

Superchargers on radial engines consist of a high-speed impeller driven through gears by the engine shaft. Surrounding the impeller are air conduits of the proper shape formed as part of the engine crank case. The only additional parts to the motor itself, therefore, are the comparatively small impeller and a pair of gears.

The Application of Turbine-Electric Drive to Ship Propulsion

Introduction—Turbine-generator Equipment—Type of Motor Drive—Main and Auxiliary Power—Control Equipment

By F. V. SMITH
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TURBINE-ELECTRIC drive holds a vital and commanding position in the modernization of marine-engineering practice. Its potentiality for effecting high economies, and its inherent characteristics which permit great flexibility of control, are factors which are rapidly revolutionizing marine standards.

In viewing the broader phases of marine-electrical installations, one of the most surprising features perhaps, to one not acquainted with ships, is the large field of engineering application involved. Unlike electrical installations on land, which are generally divided into highly specialized groups, the modern ship is a self-contained unit, which must supply all of its own needs and be self-sustaining once it leaves the dock.

There are two major problems to be dealt with in ship electrification which are closely related from an economic point of view. The first of these is that of power generation for the main propulsion of the ship; the second, that of power generation for the auxiliary needs. The relation that these two power needs hold, one to the other, proves many times to be a potent factor in the selection of the proper type of electrical equipment for a vessel.

The auxiliaries on a vessel consist briefly of those which function in connection with the operation of the main power plant; those which are necessary to make a ship habitable; those used in connection with cargo handling; those which are installed as a navigational aid; and those which provide for the safety of the ship.

The auxiliary equipment on a vessel may be either simple or extensive depending upon the specific type of ship under consideration and its duty; the auxiliary power requirements of the modern, high-speed, combination passenger and freight vessel gives a very good example of the many engineering problems involved. Under the heading of auxiliaries which are installed to make a ship habitable may be mentioned the lighting, water, heating, ventilation, refrigeration, fire main, interior communication, and sewage systems which are comparable in every way to similar systems required in large hotels, or those which supply the needs of a small city. Provision must also be made for making fresh water at sea and large evaporator plants are installed for this purpose. The auxiliaries installed for cargo handling consist of winches, elevators, and special types of apparatus for loading and unloading the vessel. Under the head of auxiliaries used as an aid to navigation appear such items as steering gear, radio, searchlights, capstans, warping winches, and anchor windlass. Those which provide for the safety of the ship consist of motors for operating water-tight doors, boat cranes and hoists, and pumps for emptying water from the holds of the ship.

It is obvious from central-station operating practice that when the auxiliary needs are as extensive as those outlined, the matter of laying out a well-balanced plant and the securing of a proper heat balance is no mean problem.

Before the advent of complete ship electrification, and when connection between the prime mover and the propeller shaft was made by mechanical means, and the auxiliaries were all steam driven, a proper heat balance was almost unknown. The auxiliary power, when considered on a steam basis, ranged from 25 per cent of the total steam produced at the full powering point of the main propelling machinery, to as high as 50 and 60 per cent at reduced powers. As it was also general practice to operate all of the steam auxiliaries on a non-condensing basis, means had to be found for disposing of the large quantity of auxiliary exhaust steam which was in excess of the feed water heating requirements. On some of the older types of vessels it was common practice to pipe this excess steam directly to the main condensers.

One of the later methods of taking care of this excess steam was to admit it to the main turbines. For simplicity of design, it was also the generally accepted practice to provide but one opening in the turbine for this purpose; as the pressure stage selected would be one that would permit the steam to enter the turbine under full power conditions, large throttling losses occured when operating the vessel at reduced power, and little good came of the steam so introduced. There were also many objectionable features connected with the system, such as turbine-blade erosion, and the carrying of oil over into the condensers. The auxiliary exhaust lines which came from remote parts of the ship carried excessive moisture and the quality of the steam was therefore of very doubtful value for utilization in the main turbines under any circumstances.

From an economic point of view the steam auxiliary system was responsible for many hidden losses. Steam at boiler pressure could not be utilized by the reciprocating pumps and it therefore became necessary to provide reducing valves in the steam lines with their attendant available energy losses. The mixed-pressure type of turbine also increased the quantity of steam entering the condenser, which in turn either increased the duty of the condenser auxiliaries, or resulted in a lowering of the vacuum, with a resulting power loss on the main propelling equipment.

The modern all-electric vessel has as one of its principal objectives the realization of maximum economy through the planning of a well balanced engineering plant. This can be accomplished on a ship the same as it has on shore, as has been proved by the two late installations on the modern passenger liners S.S. *California* and S.S. *Virginia*.

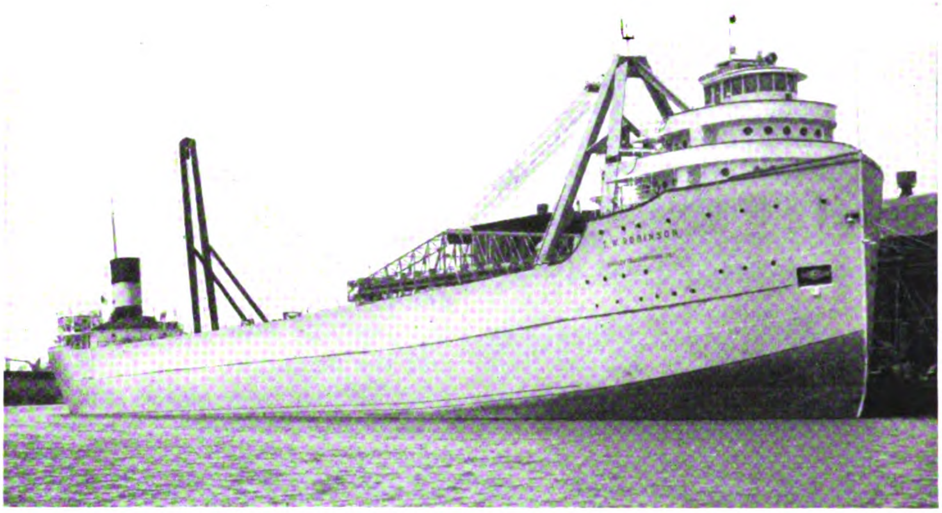

Fig. 1. The Electrically-propelled Self-unloading Bulk-freight Carrier S.S. *T. W. Robinson*

The propulsion power equipment on a turbine-electric driven vessel consists of the main turbine-generators, the propelling motor or motors, and the control equipment for maneuvering the vessel. The degree of flexibility and the number of electrical combinations which can be effected in the handling of the power throughout the speed range of the vessel is limited only by the number of main power generating equipments installed, the number of propellers, and the number of propelling motors connected to an individual propeller shaft.

In twin-screw vessels it is usual practice to install two main generating equipments and one propelling motor on each shaft. This combination permits both propellers to be operated from either one of the main generating equipments at reduced power, and for one generator to supply the power to an individual propelling motor under full power conditions.

On quadruple-screw vessels either one or two propelling motors may be connected to each propeller shaft, and either two or four main generating equipments installed. The four-generator and eight-motor combination gives a wide choice of power distribution. All of the propellers can be operated from any one of the main generators at reduced power and generating equipments added as the power demands increase.

TURBINE-GENERATOR EQUIPMENT

The type of turbine-generator equipments that are applicable in marine installations do not differ materially from those used in central stations ashore, and the same economical design measures are as applicable in one case as the other. One of the principal differences from an operating point of view is that the marine type of turbine generator operates on a variable-speed, variable-load basis, whereas the central station turbine generator operates on a constant-speed, variable-load basis. In marine installations the nature of the propeller load must also be taken into account in order that the designed, combined generator and motor characteristic provides ample torque margin for heavy sea operation. The propeller torque varies through quite a wide range at constant revolutions, both on account of the sea and the action of the rudder. Other considerations consist of the propeller-torque characteristics while maneuvering.

The selection of the designed speed of the turbine-generator for best economy is given a wide latitude of choice in marine installations because the frequency is of no importance. The number of poles in the motor can also be selected in the same way to give the propeller speed characteristic desired.

The installation of the turbine-generators on a modern vessel follows closely the accepted practice on land, *i.e.*, they are of the downward exhaust type and mounted directly above their respective condensers. In late installations air coolers for the generators are also provided.

On account of the wide variation in the propeller speed required at sea the method of turbine speed control necessarily differs from that on land. The turbine is supplied with a speed-control governor, and numerous hand valves for effecting different nozzle combinations. When the ship is at sea under steady operating conditions the hand valves are adjusted to give the speed desired; the speed governor is then set slightly above the speed obtainable with the given hand valve setting. The equipment therefore operates on a constant steam flow basis which in turn makes for steady operation of the boiler plant. Should the propeller emerge from the water however, suddenly releasing the torque on the propelling motor, the speed governor functions and keeps the propeller from speeding above that of the governing setting.

TYPES OF MOTOR DRIVE

There are two types of alternating-current motors that have practical application on ships—the induction motor of the wound-rotor type, and the synchronous-induction type. The question is asked many times why it is that in some cases one type is used in preference to the other. A study of the individual characteristics of both types of motors, it is believed, will bring out these points quite clearly and show the basis of the reasoning back of the decisions made in each case.

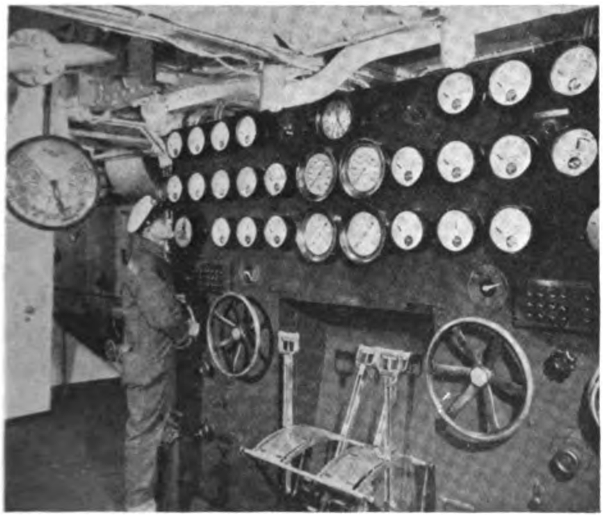

Fig. 2. The Main Control of the Operating Panel of the S.S. *Virginia*

Induction Motor Drive

The induction motor with two different sets of pole connections is a type developed principally for naval applications. On major vessels of the battleship, or airplane carrier type, long cruising radius at reduced speeds and economy at these reduced speeds is of great peace time importance. When operating with but one generator, the turbine speed would necessarily be reduced in proportion to the propeller speed providing but one set of pole connections were provided on the motor. The capacity of the generator and the economy of the turbine would also be reduced under such conditions. The two sets of pole connections on the motor therefore allow the electrical gear ratio to be changed to suit the operating condition, and the turbine-generator speed to be raised; hence, full power output is had at approximately the same economy as at full power. The induction type of motor with two different sets of pole connections has been used on all large naval vessels. The overall economies are also greatly enhanced, because when one or more generating equipments are shut down, the attendant condenser and auxiliary equipments may also be shut down. Electric drive is the only form of ship propelling machinery in which these two features are provided.

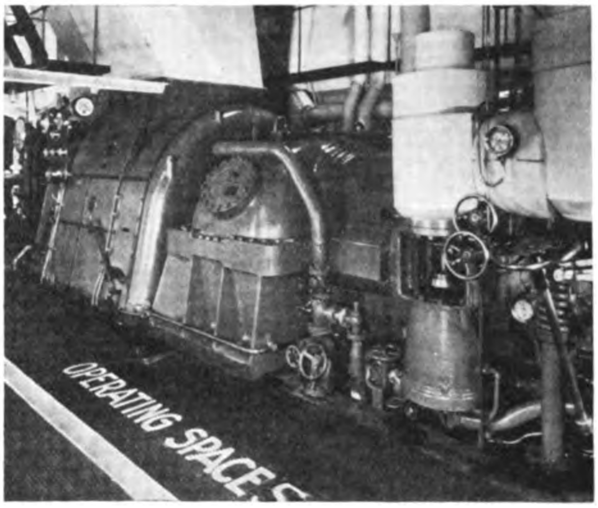

Fig. 3. One of the Two Main Turbine-generators of the S.S. *California*

The induction type of motor has also been applied to merchant vessels and yachts, but for very different reasons than the pole-changing feature. In merchant-ship applications it is general practice to apply the wound-rotor, slip-ring type of induction motor; this type of motor may be phased in at relatively high speeds of the turbine-generator by means of resistance inserted in the secondary windings of the motor. It therefore adapts itself to ships in which the main generator supplies power for auxiliary purposes in addition to that of propulsion.

Main and Auxiliary Power Combinations

The most economical type of ship installation, from the viewpoint of overall economy, would obviously be one in which the main generating equipment furnished power simultaneously for both propulsion and auxiliary purposes without any conversion requiring additional apparatus. This is not possible, however, when alternating-current machinery is used because of the speed variations required on the main propellers.

The effectiveness with which these dual drives may be worked out in practice depends upon the type of ship, its specific duty, and the type of main propelling machinery installed. Several different methods of accomplishing very economical results with the installation problems involved will be briefly described.

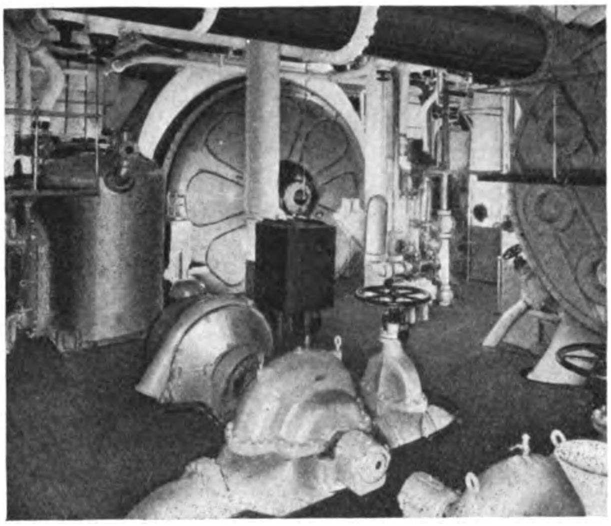

Fig. 4. Engine Room, Showing Motor-driven Circulating Pumps in Foreground, S.S. *California*

In many types of vessesls the speed range while under way is practically constant, low propeller speeds being required only when maneuvering. Such auxiliaries as can be conveniently driven by alternating-current motors may therefore take their power directly from the main propulsion power cables when such ships are under way. Direct-current power, which cannot be dispensed with entirely on ships because of the excitation requirements and the need for variable speed motors for special duty, can be furnished by conversion, or by a direct-connected exciter. In applications of this type, the propeller speed is altered, through a definite speed range only, by turbine speed control; and the lower maneuvering speeds accomplished by means of a multi-step resistor placed in the rotor circuit of the motor. The alternating-current motors used for auxiliary purposes and the exciter set are designed for maximum power output at the lowest speed obtainable by turbine speed control. The resistance loss is a minor factor on account of the limited period of time in use, and the economic gains are quite large while under way.

In installations which require a large variation in propeller speeds while under way other methods must be adopted. This may be accomplished by means of a separate three-unit set, consisting of an a-c. motor, d-c. generator, and a relatively small turbine, all connected in tandem. When the ship is cruising at relatively high speeds the a-c. motor, which derives its power from the main power cables, drives the d-c. generator; the turbine idles under this condition of operation. Should the speed of the main turbine-generator fall below a certain definite point, an automatic control device opens the steam valve to the small turbine of the three-unit set, which is now used to drive the d-c. generator and may drive the a-c. motor as a generator. As a general rule the point selected for change over from motor to turbine drive is approximately ¾ maximum speed. Constant voltage is maintained at the direct-current generator terminals by means of a voltage regulator.

Generally speaking, the auxiliary load on a small vessel is of a greater percentage of the total than on a large vessel, and it therefore becomes of greater importance to resort to some stringent means for the securing of cheap auxiliary power, if a well balanced and efficient power plant be the main objectives.

There are also special types of vessels, such as self-unloading ore carriers on the Great Lakes, in which the auxiliary needs in port are very extensive, and in which a certain amount of maneuvering is required simultaneously with the loading and unloading operations. For such vessels it is therefore of economic importance that the main powering units be designed to perform a dual service and at the same time incorporate flexibility of control.

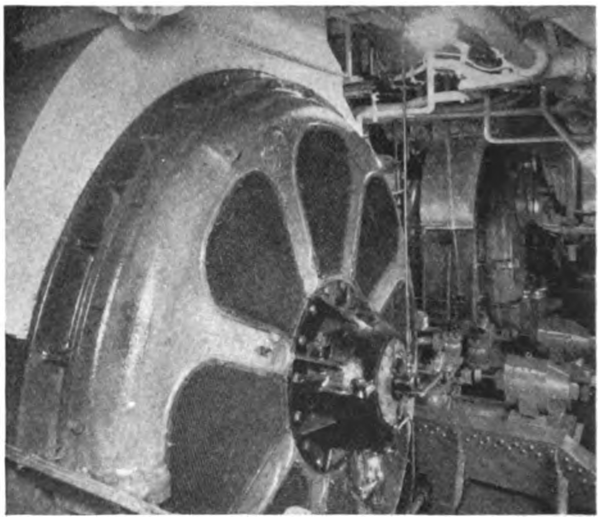

Fig. 5. Main Propulsion Motor, of the Synchronous-induction Type, Installed on the S.S. *California*

The induction type of motor fulfills a very definite need in such cases on account of the resistance method of securing low propeller speeds, thus permitting the main generating units to be used for dual purposes.

In high-powered vessels, in which the auxiliary power requirements are extensive, the auxiliary turbine generators are quite large, and the economies of the units more comparable with that of the main power plant. The applications of dual drive therefore becomes of lesser importance; and individual power plants for each service can be used.

SYNCHRONOUS MOTOR DRIVE

The marine type of synchronous-induction motor possesses the characteristics of high efficiency and unity power-factor, and therefore finds a large field of application in marine practice. In the marine type of synchronous motor an induction type of squirrel-cage winding is imbedded in the pole faces of the motor, which is used for bringing the motor up to speed before applying excitation to the field windings of the synchronous motor. The synchronous type of motor differs from the induction type because a definite electrical gear ratio exists between the generator and motor speed at all times; all variations in propeller speed are therefore accomplished entirely by varying the speed of the turbine-generator.

The principal field of application of this type of propelling motor is that of large commercial vessels which operate continuously on definite trade routes, or vessels in which it is of little economic importance to use power from the main units for auxiliary purposes. Its field of application therefore lies in the direction of the large passenger liner and high-speed freight vessel.

The synchronous-induction type of motor is highly efficient and as the powering system operates on a unity-power-factor basis, the equipment can be generally designed much lighter in the high-powered regions.

The S.S. *California* and the S.S. *Virginia*, the two largest passenger vessels ever built in this country, which are operated on the Panama-Pacific Lines of the International Mercantile Marine Co., and their new vessel, the S.S. *Pennsylvania*, which is now building, are powered with synchronous-induction types of marine propelling motors.

The Grace Line is building a passenger liner for their South American trade route, and the Ward Line is constructing two passenger liners for their Havana-New York trade route. These vessels are likewise to be propelled by the synchronous-induction types of motors.

On ships which are powered with the synchronous-induction type of motors and which are twin or quadruple-screw, and have two or four main generating equipments installed, the motors can be paralleled for operation from one generating equipment as in the case of the induction motor drive, as previously explained. With half of the main generating equipment closed down, approximately 75 per cent of the ship's maximum speed can be maintained without overloading the generators in use.

CONTROL EQUIPMENT

The control of an electrically driven vessel while maneuvering is accomplished rapidly and easily. The three-phase alternating-current system is invariably used in merchant ship applications, and therefore the reversal of the direction of the propelling motors requires only the altering of the juxtaposition of two of the three main current-carrying leads. Contactors are provided for this purpose which are actuated by means of a reversing lever placed on the operating panel.

The field-control system of the main powering equipment is also controlled by means of a single lever. The general method of reversing the propellers on an electrically driven ship consists of simply reducing the turbine speed, pushing the field lever to its "off" position, pushing the reversing lever to the "ahead" or "astern" position as desired, and again applying excitation to the fields by means of the field lever. These operations take but a few seconds and may be accomplished rapidly enough to suit any real need or purpose.

All of the control mechanism for maneuvering the vessel, and the instruments, meters, and gauges necessary to give the engineer complete information regarding the operation of the plant, are installed on one operating panel. Power readings are constantly available and therefore a very close check can be made of the operating efficiency of the vessel at all times.

The great flexibility of electrical machinery makes it the ideal type for ship installations. The reliability of a vessel is greatly enhanced through the various power comibinations which are provided and the economy is of the best and in the future can keep pace with modern practice ashore.

As to the sphere of application of the induction, and synchronous-induction types of marine motors, it is not likely that one type will supersede the other but that both types will find universal application in their respective fields, which can only be determined after a special study is made of the individual ship's needs.

Burn-out of Incandescent Lamps

A DISCUSSION OF THE PHENOMENA INFLUENCING THE LIFE OF GAS-FILLED LAMPS

By GORTON R. FONDA
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Introduction

THAT the present incandescent lamp with tungsten filament has been brought to a high state of perfection is common knowledge. In addition to the advantages coming from the fundamental researches on drawn wire and on gaseous filling, there have been notable achievements on the part of the development laboratories and engineers of the Incandescent Lamp Department. They have not only succeeded in obtaining the inherently high efficiencies possible; they have taken full advantage of all the inherent, incidental features and have produced lamps of remarkable strength. Due to modern skill, the human individual is now counting on attaining fully his allotted life of three score years and ten, unless interrupted in his course by some act of positive violence. Lamps have been similarly fortunate. Their physical character is now such that they are capable of surviving all of the ordinary hazards and attaining a life which is limited only by exhaustion of the filament, caused by what is known as "burn-out."

In view of this, it is well to scrutinize the condition of the lamp at the moment of burn-out, to ascertain if it has in fact given as much service as is consistent with efficient use. The great majority of lamps are used on constant voltage circuits. During life the filament evaporates continuously and thereby becomes thinner. Its resistance consequently rises and its temperature falls, and with it of course the candle power. Theoretically this process should proceed until the filament has become the merest shred of its original self, ready at the next moment to evaporate completely. Such a course would be disastrous for the user, unless he were wise enough to replace the lamp with a fresh one, for the candle power would have fallen off to negligible values. Fortunately, however, there is bound to be some point in the filament which, from one of several possible causes, will eventually evaporate more rapidly and thereby be raised to a higher, localized temperature until it reaches the melting point. Thereupon the filament "burns out" at this point.

In a vacuum lamp the burned-out terminals are of reduced diameter with beads of metal at their ends. In gas-filled lamps the phenomenon is more complicated. The presence of the gas allows the higher pressure of tungsten vapor evaporating from a hot spot on a particular coil to deposit on adjacent coils, building them up to enlarged diameter—a distinctive case from that in vacuum, where all tungsten vapor proceeds unrestricted to the bulb. In Fig. 1 is shown the development of such a failure in gas. The pictures are negatives, taken by direct exposure to the incandescent filaments, so that the blackest parts represent the highest temperatures. They show the development of a hot spot and its passage into a case of "spot-evaporation." Burn-out of the thin coil is sometimes followed by a welding together of the two terminals, giving an offset appearance to the filament. This result is typical of the final failure of gas-filled lamps. In abnormal cases it is produced early in life by the presence of water vapor.

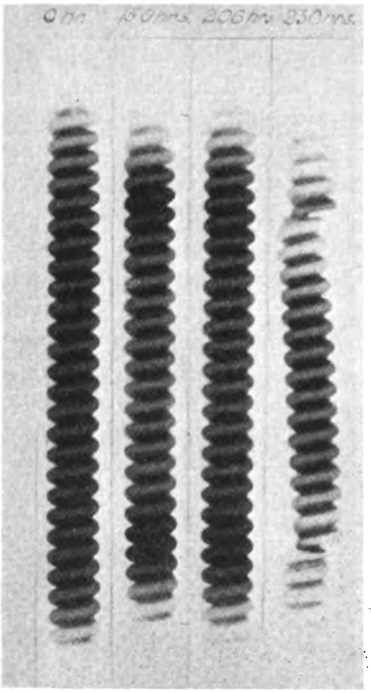

Fig. 1. Development of Spot Evaporation, 6.6-amp., 60-c-p. Street Series Lamp, Tested at 7.1 Amp.

For the vacuum lamp, failure is reached when the filament has lost about ten per cent in weight. This is well placed from the standpoint of efficiency, for it is such that the average candle power of the lamp during life has decreased about ten per cent below its initial value, and this is recognized as within the bounds for good service.

The gas-filled lamp offers an entirely distinct case. Its average candle power during life decreases only about five per cent. Some of this is due to the extreme localization of the evaporated tungsten, which collects at one spot on the bulb instead of being distributed generally over its surface as in the vacuum lamp. Another factor has entered, however, for it is found that burn-out of the filament has occurred at less than five per cent loss in weight—less than half that for the vacuum lamp.

This is demonstrated by the curves in Fig. 2 which show the relative changes in current during life for some vacuum and gas-filled lamps, adjusted to such efficiencies that the burn-out life of each was just 1000 hr. They show that the vacuum lamp burned out at about ten per cent decrease in current (and therefore in weight) and the gas-filled lamp at about three per cent. In both cases the filaments were of coiled wire. This is of no consequence on the results, at least for the vacuum lamp, for the type of the latter with straight filaments showed the same rate of current decrease and burned out at about the same value.

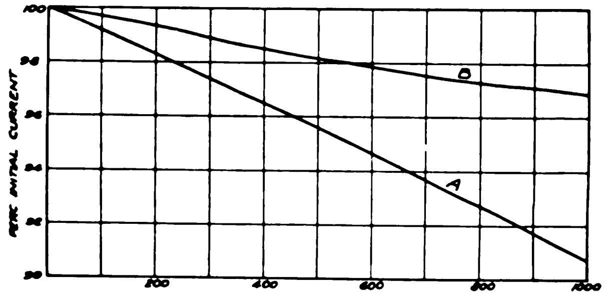

Fig. 2. Decrease of Current During Burn-out Life of 1000 Hours

(*A*). 25-watt, 115-volt, Vacuum Lamp
(*B*). 60-watt, 115-volt, Gas-filled Lamp

This difference has been verified by tests on straight filaments of short lengths, made up into the loop shape of the now obsolete hairpin. Those in vacuum burned out at about twenty per cent loss in weight, whereas those in a mixture of 86 per cent argon and 14 per cent nitrogen burned out as early as about nine per cent. These values are in a higher range because of the shorter lengths of filament involved, but the relation is the same.

Such a distinction raises an interesting point for controversy. What should be the engineer's attitude toward the gas-filled lamp, under this characteristic difference from the vacuum lamp? Should he be grateful for it, as a means of attaining a lamp of more nearly uniform candle power throughout life? Or should he recognize the performance given by the vacuum lamp with its poorer candle power maintenance as a proper standard for governing efficient use and endeavor to bring it about that the filament of the gas-filled lamp should burn to as great a loss in weight as that of the vacuum lamp?

Such an achievement would have one notable result. It would allow the initial efficiency of the gas-filled lamp to be raised about 10 per cent for the same burn-out life. Furthermore, it might be particularly valuable in the case of projection lamps which could be so designed that all of the discoloration would form outside the light path.

This is an achievement, however, that it has been impossible yet to attain. Just the reason for the characteristic low loss in weight of the filament at burn-out in gas has so far evaded definite discovery. It is probably due to several contributing causes. In the narrative which follows, some possible causes are taken up and discussed from the standpoint of tests bearing on them. They involve consideration of the hot tensile strength and the modes of crystalline changes in tungsten, the possibility of disintegration of the filament under chemical changes, and the influence of ionization of the gas. They do not solve the problem; they only draw attention to some of the features which may bear upon its solution.

Tensile Strength of Tungsten

The strength of cold, drawn tungsten wire is remarkably high, about 580,000 lb. per sq. in., higher than that of steel wire. After the wire has been heated sufficiently to recrystallize it into the equiaxed condition, its strength becomes considerably less, about 140,000 lb. per sq. in.

As the strength decreases, of course, with rise in temperature, it is conceivable that at the very elevated temperatures of gas-filled lamps, 2700—3500 deg. K., it would fall off to such low values that the continually applied force of the filament's own weight would become a factor of importance.

On the one hand it might disrupt the crystalline lattice. A drawn wire can be coiled in any way without affecting its life in this respect, because crystallization takes place after the coiling operation. Once the wire is crystallized, however, coiling is fatal—the elastic limit of the crystalline lattice is exceeded, the lattice is broken up into crystalline fragments (that can be detected by x-ray analysis, not by the microscope), and this disintegration causes early failure when the filament is burned. A single crystal filament for instance, which would burn in vacuum normally to a 23 per cent loss in weight, burned out at a 10 per cent loss in weight after coiling and uncoiling on a 600 per cent mandrel. A drawn wire of the same size was unaffected.

Another possibility is the formation of slips by plastic deformation under the force of the filament's weight while burning. Out of many hundred tests on loop filaments, it was notable that the position of burn-out in vacuum was haphazard and that in gas the failure was almost invariably at a point about 12 mm. from the leads from which the filament was suspended. The filament above this point was cooled more and more by the leads, so that this point represented the point on the filament at full incandescent temperature which had the maximum length and weight of filament below it as a stress.

In order to find possible distinctions between different kinds of wire, measurements were made on the tensile strength of three types of filaments at incandescent temperatures in vacuum. One was the "218" wire developed for gas-filled lamps because of its long grain, sag-resisting qualities. Another was a fine grain wire containing 1.5 per cent thoria, which for convenience can be called "E" wire. The third was Pintsch wire, a single crystal product, containing about 2 per cent thoria. The results are shown in the curves in Fig. 3, which brings out the characteristic differences between them.

In Fig. 4 are given photomicrographs of the fractured ends of the 218 wire at two typical temperatures. The upper (A) shows the slips of plastic deformation which took place within a grain at temperatures below 3000 deg. K. At higher temperatures the grain boundaries became weaker than the crystalline material of a grain, so that fracture was intercrystalline, as shown at (B), with no plastic deformation.

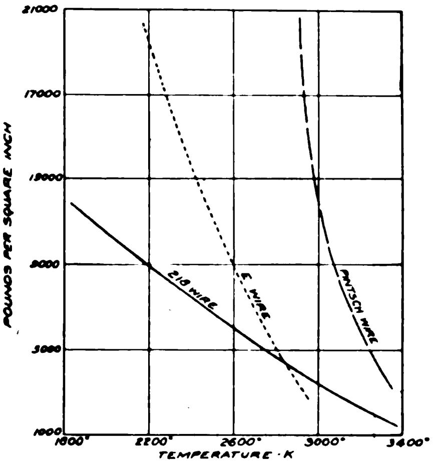

Fig. 3. Hot Tensile Strength of Tungsten Filaments

The plastic deformation of Fig. 4(A) resembles closely what can be observed in filaments tested in gas. In Fig. 5 is shown an enlarged picture of the surface of a filament which had been burned until a spot of local high temperature was observed. Fig. 5(A) is just above the spot. The reduced diameter of the latter, shown at Fig. 5(B), denotes that the hot spot was formed by a thinning of the wire rather than by a rise in resistivity. The peculiar markings in Fig. 5(A) resemble the slips of Fig. 4(A). The occurrence of slips would indeed have reduced the diameter sufficiently to give a local hot spot, which would then have been reduced in diameter further by excessive evaporation.

The curves in Fig. 3 denote that "E" wire is stronger than 218 wire at temperatures below 2900 deg. K., and weaker above. To confirm the significance of this, forced life tests were made in vacuum with weights attached to loop filaments. At 2300 deg. K. under a stress of 7400 lb. per sq. in. the life of "E" wire was 66 seconds as contrasted with 4 seconds for 218; at 3000 deg. K. with a stress of 500 lb. per sq. in. the life of "E" wire was 13 seconds and that of 218 wire 38 seconds—all in proper agreement with the differences in tensile strength.

Again, Fig. 3 shows a much higher strength for Pintsch wire. Tests at 2600 deg. K. under a stress of 5000 lb. per sq. in. showed a life of 150 minutes for Pintsch wire and only 10 seconds for 218 wire.

The question was therefore raised—would life tests on these filaments in gas show similar differences which would be reflected in the percentage loss in weight at burn-out? Tests of "E" and 218 wires at 2540 deg. K. and 3125 deg. K. showed no appreciable differences. In tests on Pintsch and 218 wires at 2720 deg. K., the 218 wire burned out at 5.4 per cent loss in weight. The Pintsch burned to 6.6 per cent, a slight but significant difference, which might be interpreted as denoting a greater resistance to tensile strength. If the stress is of importance, though, it is evident that its effect is more far-reaching than can be influenced to any marked degree even by the wide differences in tensile strength shown by two such distinct wires as Pintsch and 218.

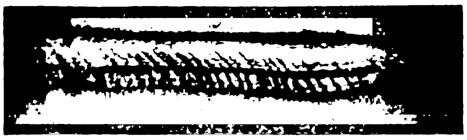

Fig. 4(*A*)

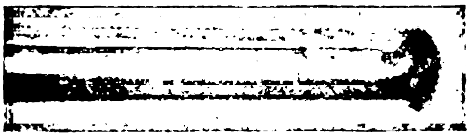

Fig. 4(*B*)

Fig. 4. Fractured Ends of 218 Wire After Tensile Test

(*A*). At 2000 deg. K
(*B*). At 3350 deg. K
Magnification 100 diameters

A still more severe test of the hypothesis was made. If the weight of the filament alone, amounting to about 0.7 lb. per sq. in., is sufficient to cause burn-out at such a slight loss in weight, then, it was argued, the addition to it of considerably heavier weights should cause burn-out at a still lower loss in weight. A life test of loop filaments, 0.004 in. in diam., was carried out at 2870 deg. K. in 86 per cent argon with these results:

Stress of Suspended Weight Pounds Per Square Inch	Per Cent Decrease in Weight at Burn-out
0	10.3
1.7	10.5
8.2	10.6
16.5	9.2
24.7	8.9
33.0	8.3

Here is an unmistakable trend toward lower values as the weight is increased, but not at all as extensive a one as the hypothesis would seem to call for. It is, of course, true in general that initial plastic deformation takes place comparatively readily under a slight load, below its equiaxing temperature, and that the test piece is thereby rendered more resistant to yield under higher loads. In this case the slight load of the filament's weight might produce enough deformation to form a hot spot, but one would hardly expect at this high temperature that the resistance to further deformation under higher loads would be increased. On the whole, one must conclude that the tensile stress of the filament's weight is unimportant.

Ionization Effects in Gas

There is a significant difference between vacuum and gas-filled lamps in regard to the possibility of "arcing." This term is used to denote the occurrence between the filament terminals of an electric discharge which short circuits the filament. In a lamp having a high vacuum the thermionic current between the terminals is limited to such an insignificant value by the space charge of electrons that arcing is impossible; an evolution of a very low pressure of gas causes an immediate arc however, because of the ionization of the gas, with consequent reduction of the space charge and a building up of a high current across the gap.

In gas-filled lamps arcing cannot take place readily because of the difficulties offered to ionization by the high pressure of gas. In order that an electron may ionize a gas molecule by collision with it, the electron must first have traveled a sufficient distance under the applied field to acquire the necessary potential. If it collides with a molecule such as nitrogen before attaining this potential, its accrued energy is transferred to the nitrogen molecule as kinetic energy and it must start off afresh to acquire its ionizing potential. Ionization is therefore most notable in low pressures of gas, where collisions are relatively rare; and it is comparatively infrequent at high pressures. Under suitable conditions, however, it does take place. In gas-filled lamps, for instance, arcing occurs immediately if the terminals are placed too close together, for this increases the potential gradient and thereby allows an electron to acquire a greater potential between collisions.

Inasmuch as arcing is possible in gas-filled lamps, it is obvious that even in normal lamps there may be leakage currents due to ionization of sufficient magnitude to overheat those portions of the filament between which they play and thereby lead to early burn-out. It was felt to be desirable, therefore, to measure these currents and then to determine by suitable tests if they could be injurious.

The method involved mounting in a bulb two five-mil loop filaments, 9 cm. long and 1 cm. apart, heating them to various temperatures, and measuring the current passing between them on application of direct-current potential. With increase in filament temperature the volt-ampere characteristics in vacuum remained constant for the reason that the current was limited by space charge. In the presence of gases, however, the current at any one voltage increased continuously with rise in temperature, particularly in the higher voltage range where one would expect ionization to be most marked.

A typical set of curves is given in Fig. 6 for the temperature of 2600 deg. K. at which the current in both 86 per cent and 100 per cent argon became greater than that in vacuum at moderate potentials. The shapes of these curves are also of interest, the abrupt portion denoting the beginning of intensive ionization. The effect of nitrogen in reducing the current is striking. Collision of a low-velocity electron with a nitrogen molecule results in a very much greater loss of the electron's energy than a collision with argon. The potentials at which an arc was struck varied correspondingly—130 volts for 100 per cent argon, 400 volts for 86 per cent argon, and above 700 volts for pure nitrogen.

When the gas pressure is decreased, the current under constant potential increases, as this change favors ionization. This gave an opportunity to test the effect of leakage currents of various magnitude on the burn-out of filaments. Loops of four-mil wire

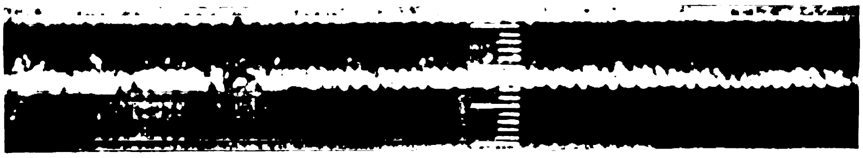

Fig. 5(*A*)

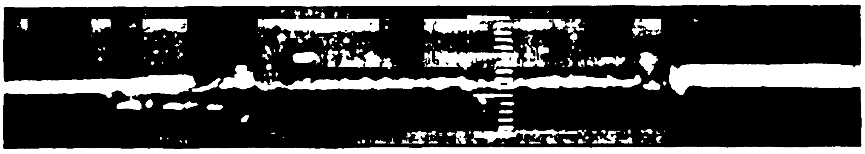

Fig. 5(*B*)

Fig. 5. Surface of 218 Wire at First Appearance of Hot Spot

(*A*). Just above hot spot (*B*). At hot spot

Magnification 150 diameters

were chosen and tested at 2870 deg. K. in various pressures of 86 per cent argon. A comparison was made with the leakage currents between two incandescent filaments at a potential of 20 volts. The results are shown in Fig. 7. In no case was there arcing or any visible signs of a discharge. At pressures below 100 mm., where the leakage current was rising abruptly, the effect was evidently very marked—burn-out occurring as early as a two per cent loss in weight at a pressure of 10 mm. and in a vacuum deferred to a twenty per cent loss, with a life three times longer despite the higher rate of evaporation. It is true that the range of pressure at which the ionization current became of noticeable effect is well below the pressures which are generally employed, but the demonstration that the effect does exist is significant.

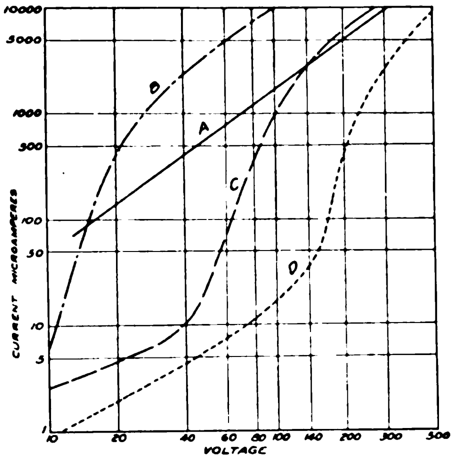

Fig. 6. Leakage Currents Between Two Parallel Filaments, 1 cm. Apart and at 2600 deg. K.

(*A*). In vacuum
(*B*). In 100 per cent argon 60 cm. pressure
(*C*). In 86 per cent argon 60 cm. pressure
(*D*). In nitrogen 60 cm. pressure

Instead of reducing the gas pressure as a means of increasing the leakage current, a similar though not as extensive an increase results by reducing the distance between the two electrodes. It was found that under constant potential and a gas pressure of 60 cm. the current increased inversely with the spacing, following an exponential law. This is a consequence of the greater potential drop experienced by an electron between collisions, as has been explained.

The normal increases are exaggerated if the space between the electrodes is heated locally. The expansion of gas which takes place is equivalent to a reduction in pressure and this gives the electron a still greater chance to acquire its ionizing potential between collisions. This was demonstrated by a test in which an auxiliary filament was placed below the two incandescent filaments comprising the electrodes. When the auxiliary filament was lighted, so as to produce a rising convection current of hot gas between the electrodes, the current between them doubled under the same potential difference, and the voltage necessary to start an arc between them decreased by twenty-five per cent. This test is significant for lamps, for it happens occasionally that effects occur in them which can be traced to the filament design and to hot convection currents produced by it.

In view of these increases of leakage current which accompany closer spacing, a test was made to find the possible relationship with burn-out. Loop filaments of four-mil wire with various spacings between their terminals were life tested at 2870 deg. K. in 60 cm. of 86 per cent argon. The potential across them was about 30 volts. The results showed the relationship expected:

Mm. Spacing	Per Cent Loss in Weight at Burn-out
20	10.3
5	9.4
4	7.5
2	Arced across immediately

These effects again do not explain the great drop in the loss of weight at burn-out which is characteristic of gas-filled lamps as compared with vacuum lamps. In both tests, involving reduced pressure and reduced spacing, it was necessary to go to abnormal conditions before an effect could be observed. Both tests do demonstrate, however, that leakage currents may be serious to the life of the filament under conditions which favor abnormally high values for them.

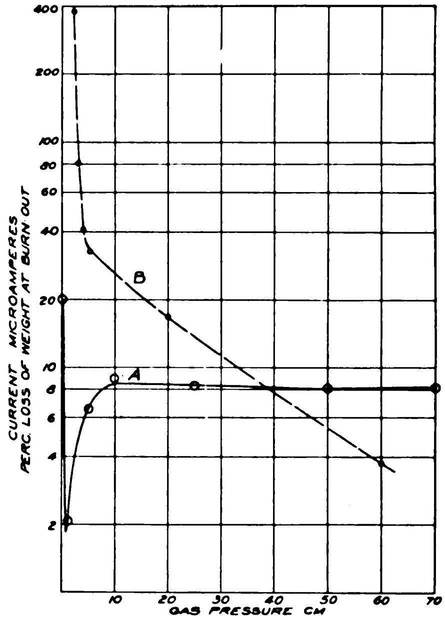

Fig. 7. Relations Between (*A*) Filament Loss of Weight at Burn-out and (*B*) Leakage Current at 20 Volts for Variation in Pressure of 86 Per Cent Argon

A possible illustration of this comes to lamp engineers in the course of testing designs of coiled filaments for gas-filled lamps. Theoretically an increase in mandrel size and a reduction in the spacing between turns should be beneficial, for they lead to reduction in the amount of heat which is lost from the filament by conduction through the gas. In practice, however, it is found that a more efficient lamp may occasionally be obtained for the same life by sacrificing some of this possible advantage and adopting, for instance, a wider spacing. This points toward the entrance of serious leakage currents when the spacing is made too close. For 115-volt lamps, the potential between turns of the coiled filaments varies from 0.2 to 0.5 volt for lamps of different size, and the spacing ranges from 0.02 to 0.15 mm. The very high temperature of gas between turns of the filament is favorable to increased ionization.

Attention also should be drawn again to the observation already cited, that burn-out of loop filaments in gas is almost invariably near the leads—the position, of course, of highest potential difference and of maximum leakage currents.

Changes in Crystalline Structure

In the course of these investigations many measurements were made on the loss in weight at burn-out for filaments of different diameter and at different temperature. A tabulation of those which are comparable shows significant trends. In the table below there are grouped the results obtained from loop filaments of 218 wire, having a total length of 12 cm., a constant spacing of 12 mm., and mounted in lamps containing 60 cm. of 86 per cent argon. The diameter of the filaments varied as noted.

Temperature	PER CENT LOSS WEIGHT AT BURN-OUT				
	0.0016 In.	0.003 In.	0.004 In.	0.005 In.	0.010 In.
2540 deg. K.	3.4				
2720 deg. K.	4.6			6.2	
2870 deg. K.	6.7	8.1	9.3	9.0	13.4
3125 deg. K.			10.3		
3300 deg. K.	8.3		12.8		

For increase in temperature as well as for increase in diameter, a filament lost more in weight before it burned out. These are curious results, not altogether to be reconciled with the discussion given. If the tensile force of a filament's weight is of primary significance, then the loss in weight at burn-out should decrease with rising temperature, as this change lowers the tensile strength of the filament. Increase in temperature brings about also an increase in leakage current as a consequence of the higher potential necessary to apply. The result from this standpoint also is the reverse of that expected. It is evident that some compensating phenomenon has entered.

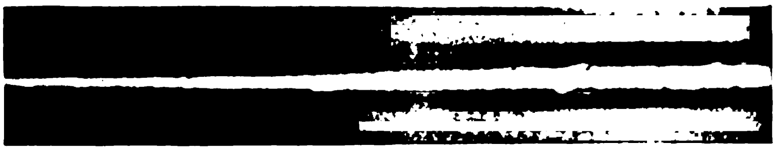

Fig. 8(*A*)

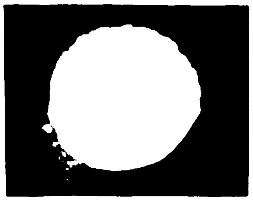

Fig. 8(*a*)

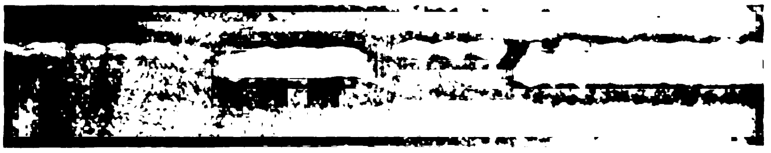

Fig. 8(*B*)

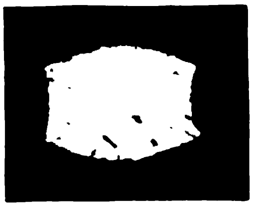

Fig. 8(*b*)

Fig. 8. Crystalline Changes of 218 Wire After Burning

(*A*). In vacuum at 2720 deg. K.—surface and cross section
(*B*). In 86 per cent argon 2720 deg. K.—surface and cross section
(*C*). In 86 per cent argon at 2870 deg. K.—cross section
Magnification—Surface 200 diameters. Cross section 450 diameters.

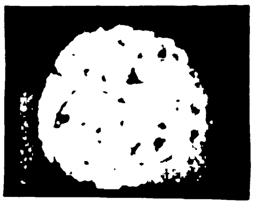

Fig. 8(*c*)

The explanation was found when attention was given to the changes that had taken place in crystalline structure during burning of the filaments. All of them had been of long grain wires. Most of the grains were large enough to fill the entire cross-section of the filament and to extend to a length equal to several diameters. In Fig. 8 are given some photomicrographs of typical ones after burn-out, chosen from the tests with 1.6-mil wire.

"A" and "B," from filaments tested at 2720 deg. K., are particularly striking. The filament in vacuum remained round and its surface uniform. The filament in gas, however, acquired a hexagonal cross-section, in accord with the natural crystalline form of tungsten. Each grain developed by itself. In general it can be said that the existence of separate grains is a consequence of differences in orientation of the material comprising them. It is to be expected, therefore, that these hexagonal crystals would be oriented differently from one grain to another. This accounts for the appearance of the filament surface shown at "B." The stretches of diminished diameter are grains whose minor axis side is turned toward the observer—the other portions are adjoining grains with the side of the major axis presented to view. Such a filament has points of diminished area between grains and, inasmuch as diminished area produces local overheating, the reason for burn-out at a low loss in weight is obvious.

At the higher temperature of 2870 deg. K. the cross-section remained more nearly round. It is, therefore, not surprising to note that the filament burned to a greater loss in weight. In fact the trend of these results with temperature is adequately accounted for by the changes in crystalline structure which produced more and more spots as the temperature was lowered.

Such changes in structures as those shown in Fig. 8 for 2720 deg. K. are a consequence of the mechanism of evaporation in a gas-filled lamp. The writer has shown elsewhere [*Physical Review 21*, 343 (1923); *31*, 260 (1928)] how a mechanism can be pictured which accounts quantitatively for the fact that large wires show a lower rate of evaporation than small ones and also for the extent to which the rate varies with changes in pressure of the gas. It is based on a conception of Langmuir that there is a stationary film of gas about a filament. When an atom of tungsten evaporates from the filament surface, it can be viewed as diffusing through this gaseous film in an irregular path governed by its collision with gas molecules. If it is successful in reaching the outer surface of the film, then it is carried away to the bulb in convection currents. However, its path may equally well lead it back to the filament and in this event it deposits upon it. The net rate of evaporation is, therefore, correspondingly less than it would be in a vacuum, where all atoms evaporating from the surface travel in uninterrupted straight lines to the bulb wall.

In the return of atoms to the filament in gas, if the temperature is not too high, some atoms can adjust their position to the orientation of the crystal on which they fall and they are more strongly held than those whose orientation is different. The latter, therefore, evaporate again more readily and the result is the formation of a cross-section in accord with the normal crystalline structure of the metal, as shown in Fig. 8(B).

As the filament temperature is raised, however, there is less and less opportunity offered for such an adjustment in position, because of the greater amount of kinetic energy characterizing the surface. More and more of the returning atoms are less firmly held to the surface and their re-evaporation proceeds, therefore, more generally. In a word, their reflection coefficient is higher. As a consequence the filament remains more nearly round, the higher the temperature at which it is operated.

The extent to which this reflection coefficient rises with temperature can be shown qualitatively by a comparison of tests in vacuum and in gas. Such a comparison has yielded the results shown below for three-mil wire. The rate of evaporation is expressed in grams per sq. cm. per second $\times (10)^9$.

Temperature	RATE EVAPORATION		Per Cent Evaporation in Gas to Evaporation in Vacuum
	Vacuum	86 Per Cent Argon 60 Cm. Pres.	
2720 deg. K.	20	0.56	2.8 per cent
2870 deg. K.	230	10.0	4.3 per cent
3125 deg. K.	2960	154.0	5.2 per cent

Chemical Disintegration

A great many tests have been made on the life of filaments in nitrogen and in the mixture of 86 per cent argon and 14 per cent nitrogen. They are all of them consistent in showing that a filament burns to a greater loss of weight in the latter. A relatively small number of tests have been made in 100 per cent argon, and in them the filament burned to a still greater loss in weight. Stated in terms of a filament 1.6 mil in diameter and 12 cm. long, tested at 2870 deg. K., the results are:

In nitrogen—4.7 per cent loss in weight at burn-out
In 86 per cent argon—6.7 per cent loss in weight at burn-out
In 100 per cent argon—8.2 per cent loss in weight at burn-out

The significance of this needs further study. On the face of it, it denotes limitations on the part of nitrogen.

Conclusion

A general discussion has been given of some of the phenomena which may influence the life of gas-filled lamps. This has been especially with the aim of noting their effect in accounting for a peculiar characteristic of these lamps—that their filaments burn out at a much smaller loss in weight than do those in vacuum.

Of the factors discussed, the tensile stress of the filament's weight appears to be ruled out as having any appreciable significance. All of the others seem capable of playing a role, greater or smaller, and the effect observed is probably contributed to by all. The effect of changes in crystalline structure is the most spectacular. Leakage currents and the chemical effects of gases are also factors of importance.

In the work that has been described, the writer has benefited by the coöperation of several members of the Research Laboratory to whom he is very grateful. He is particularly indebted to Miss Amy Walker, Miss Susan B. Leiter, Mr. A. A. Vernon and Mr. H. R. Betts.

Hot-cathode Thyratrons

PART I: CHARACTERISTICS

By DR. ALBERT W. HULL
Research Laboratory, General Electric Company

1. Introduction

THE thyratron (Greek θύρα, a door) is a three-electrode tube similar to the pliotron, into which, after exhaust, a small amount of inert gas has been introduced. The presence of gas changes the pure electron discharge into an arc, so that the thyratron is *an electrostatically controlled arc rectifier.*

As might be expected from its arc character, its behavior and electrical characteristics are very different from those of the pliotron. It is inferior to the pliotron in one important respect, *viz.*, the grid does not control the instantaneous value of the plate current but only its average value. On the other hand, it is free from the limitations to power capacity and efficiency which are imposed upon the pliotron by space-charge. The efficiency of hot-cathode thyratrons, at 500 volts and conservative (*i.e.*, long-life) rating, is approximately 97 per cent, including cathode heating. It is nearly independent of size and load-factor. The power capacity of the largest unit that has been made to date is 100 amp. at 10,000 volts. There is no apparent obstacle, either theoretical or practical, to the construction of a unit of 10 times or even 100 times this capacity.

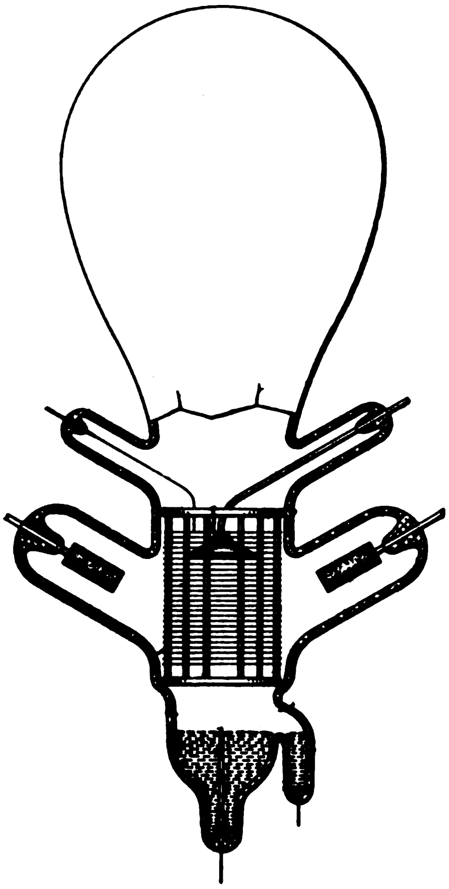

Fig. 1. Original Thyratron of Langmuir. The grid voltage controlled the time of starting

In introducing this new member of the tube family, it is necessary to emphasize its unlikeness to the preceding members, and to describe its unique characteristics. It is believed that this new tube is of sufficient engineering interest to merit a study of these characteristics, which are presented as briefly as possible. For a full account of the fundamental characteristics of gas discharges the earlier papers of Langmuir and others must be consulted.

The method of controlling a power arc by a grid was first suggested in 1914 by Langmuir, (1) who showed how to control the time of starting in each cycle by grid voltage, and so control the average arc current, using alternating anode voltage. Toulon (2) took up the study in 1922, and improved the method of control by varying the phase of the grid voltage with respect to the anode voltage. In this way he could time the starting of the arc at any desired point in the cycle, and so vary the average arc current from zero to full value.

Fig. 1 shows a sketch of the original thyratron of Langmuir, Fig. 2 the Toulon tube, and Fig. 3 a photograph of an improved form by Langmuir and Prince. The improvement consists essentially in making the grids completely surround the anodes.

The researches of Langmuir upon gas discharges, beginning in 1923, (3) laid the foundation for a thorough study of the characteristics of this kind of control. The developments to be described are based upon these researches, and were undertaken at the suggestion of Dr. Langmuir. Brief descriptions of some of the results have recently been published. (4) Further data will be published in the near future, particularly regarding the characteristics of thyratrons with mercury cathodes. The present article is confined to thyratrons with thermionic cathodes.

2. Principle of Thyratron

The thyratron is an arc rectifier the *starting* of which can be controlled by a grid. After starting, the grid has no further control over the arc, neither to modulate, limit, nor extinguish it. Herein lies the fundamental difference between the thyraton and the pliotron. Arcs can be and have been made in which, as in the pliotron, the current is continuously variable by a grid.(5) This is an advantage for some purposes, but thus far it has been obtained only at the cost of rather severe restrictions of current density and vapor pressure. Therefore that type of control will not be discussed in this article.

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(1) I. Langmuir, U. S. Pat. 1,289,823.

(2) P. Toulon, U. S. Pat. 1,654,949.
L. Dunoyer and P. Toulon, *Comptes Rendus*, p. 179, 1924; *J. de Phys.*, *5*, 257-68; 289-303, 1924.

(3) Langmuir, *Science*, *58*, 290, 1923; GENERAL ELECTRIC REVIEW, *26*, 731, 1923.
Langmuir and Mott-Smith, GENERAL ELECTRIC REVIEW, *27*, 449-55, 538-48, 616-23, 762-71, 810-19, 1924.

(4) Hull and Langmuir, *Proc. Nat. Acad. Sci.*, March, 1929.
Hull, *Trans. A.I.E.E.*, *47*, 753-63, 1928.
D. C. Prince, GENERAL ELECTRIC REVIEW, *31*, 347, 1928.

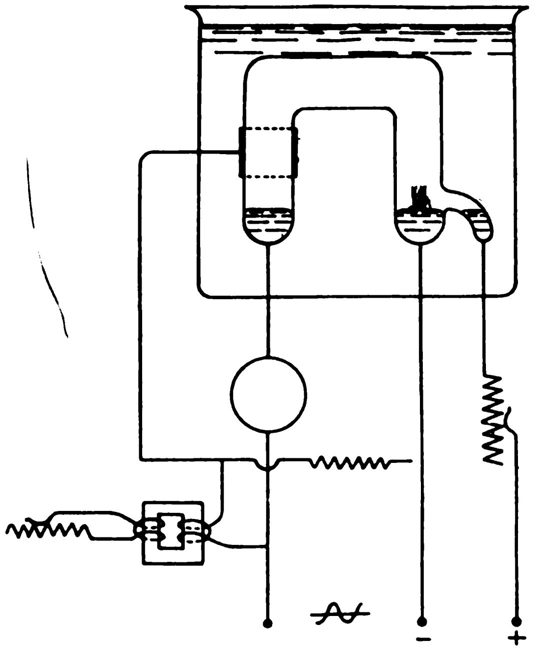

Fig. 2. Toulon Tube, with External Control Electrodes. Toulon was the first to use phase displacement between grid and anode voltages to control the time of starting in each cycle

The action of the thyratron is not confined to a single starting of the arc. It may repeat the starting operation because, although the arc cannot be extinguished by the grid, it can be extinguished by removing the anode voltage. Upon reapplying this voltage, the grid again determines whether the arc will start. By continued repetition of this process it is obvious that the grid can control the *average* current, and it is further obvious that the averaging can be made as "fine-grained" as desired by increasing the frequency of interruption. A simple method of obtaining interruptions is to use alternating anode voltage. There are other methods that can be used with direct-current voltage and they will be described in Part II of this article.

3. Positive-ion Sheaths

The inability of the grid to control or extinguish the arc is due to the formation of a "sheath" of positive ions about the grid wires.(3) This sheath acts like a layer of insulation. Whatever may be the potential of its inner surface, *i.e.*, the grid, the potential of its outer surface is always that of the discharge. The only effect of making the grid negative is thus to increase the effective diameter of its wires. In other words, a negative wire is equivalent to a slightly larger wire at zero potential. If the thickness of the sheath is small compared to that of the wire, as is usually the case, it is evident that a negative or sheathed grid will not be very different from an unsheathed grid, *i.e.*, an uncharged grid, and hence making the grid negative will not greatly influence the arc. If, on the other hand, the sheathes are made so thick (by reducing the current density) that they touch, thus completely obstructing the arc path, the arc will be extinguished; and if they nearly touch, making the arc path very narrow, the arc may be reduced. This is the principle of the continuously-controlled arc previously mentioned.

The nature of the sheath, and the factors which determine its thickness, are easily understood by reference to Fig. 4, which represents a section of a negatively-charged grid immersed in an arc. The ionized gas through which the arc is passing contains electrons and positive ions in nearly equal numbers, between 10^{10} and 10^{12} ions per cubic centimeter for an ordinary mercury arc. Since the grid is negative it will attract positive ions, but repel all electrons near it, and the same will be true of every point around the grid in which the potential is negative with respect to the arc stream. Hence all the region of negative potential around the grid wires can contain only positive ions. This region is generally visible as a thin, uniform dark space, and has been named by Langmuir the "sheath" of positive ions. Its thickness, as a function of negative voltage of the grid and positive ion current, is completely determined by space charge, and is given by the following

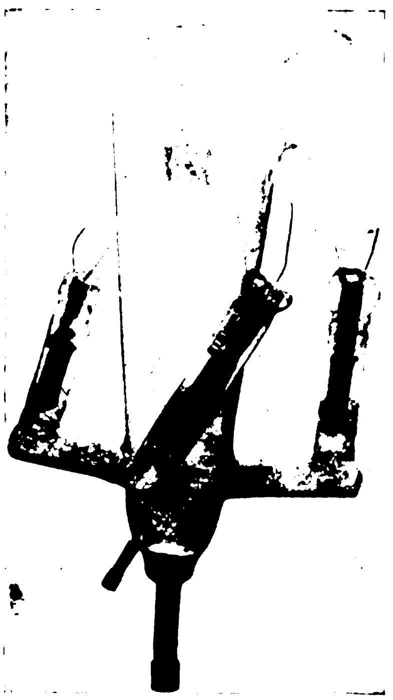

Fig. 3. Improved Thyratron of Langmuir and Prince. The grids surround the anodes

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(5) Lübcke, *Zeit fur Tech. Phys.*, *8*, 445-449, 1927.

well-known space-charge equations: For mercury ions and plane electrodes (6)

$$\frac{i}{A}=\frac{2.33\times10^{-6}}{608}\,\frac{V^{3/2}}{x^2}$$

(i = positive ion current to electrode in amperes; A = area of electrode in cm^2; V = negative potential of electrode with respect to surrounding gas, in volts; x = thickness of sheath in cm.)

For cylindrical electrodes and mercury ions (7)

$$\frac{i}{L}=\frac{14.69\times10^{-6}}{608}\,\frac{V^{3/2}}{\beta^2 r}$$

(i = ion current in amperes; L = length and r the radius of electrode, in cm.; V = negative potential of electrode with respect to surrounding gas, in volts; and β a function of a/r, where a is the radius of the outside of the sheath. The value of β is tabulated in the reference (7). The factor in the denominator (608 for mercury) depends on the mass of the ion. It is the square root of the ratio of the mass of the ion to that of the electron. For argon ions this factor is 271, for neon ions 193, and for helium 86.)

It is thus seen that for plane electrodes the sheath becomes thicker with increasing negative voltage of the electrode, in proportion to the 3/4 power of this voltage; and becomes thinner with increasing current density of positive ions (which is proportional to arc current), being inversely proportional to the square root of the current. The same is approximately true for cylindrical electrodes when the sheath is thin compared with the diameter of the wire. Hence the sheaths are very thin at high current density, and it is only in the range of low current density that they can be made thick enough, at practical voltages, to overlap and stop the arc. This furnishes the criterion for the maximum permissible residual current in a thyratron, due to residual ionization, glow discharge, electron emission by the grid, or emission from some part of the cathode not protected by the grid (see Sections 5, 8, and 9).

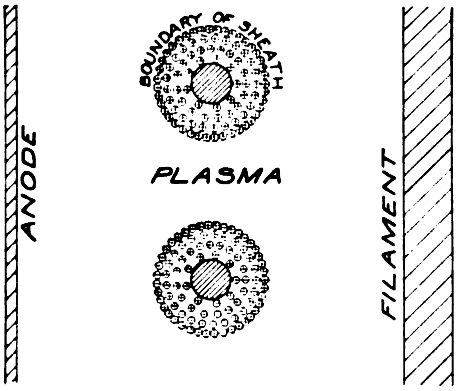

Fig. 4. Negatively-charged Grid Wires Immersed in an Ionized Gas, or "Plasma," Showing Positive-ion Sheaths Around the Wires

4. Disintegration of Cathode

The requirements of thyratron cathodes differ in two important respects from those of pliotrons. In the first place, the voltage between anode and cathode in a thyratron can and should be very low whenever current is flowing, so that positive ion bombardment, the chief foe of cathodes in power pliotrons, is harmless in properly operated thyratrons. In the second place, the absence of space charge limitation makes it possible to shape the cathodes of thyratrons very differently from those of pliotrons, and so obtain much higher electron-emitting efficiency.

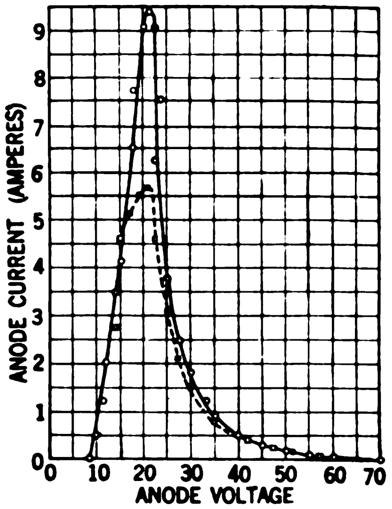

Fig. 5. Electron Emission from Thoriated Tungsten Filament at 1900 deg. K. in Argon at 0.030 mm. Pressure, as a Function of Anode Voltage. Full curve, increasing voltage; dotted curve, decreasing voltage

The statement that positive-ion disintegration may be less serious in a gas-filled tube than in a high-vacuum tube requires justification, as it is exactly contrary to most past expereince. Its truth depends upon the fact, which has been thoroughly established, (8) that *positive ions do not cause disintegration when their velocity is below a certain value;* and upon the discovery of precautions for keeping the velocity below this value. The precautions are partly a matter of tube design, *i.e.*, of proper cathode structure and gas pressure, and partly of operation. They will be considered later in connection with these subjects. The net result to be accomplished is definite and may be very simply stated:

The maximum voltage between cathode and anode, when current is flowing, must be kept below the "disintegration voltage" of the gas. The disintegration voltage is fairly critical for each gas, and lies between 20 and 25 volts for the inert gases and mercury. Neglect of this precaution is responsible for the failure of most of the attempts to use gas in thermionic tubes in the past.

The existence of a definite "disintegration voltage" for positive ions is best illustrated by the behavior of "thoriated" tungsten filaments, whose electron emission is mainly due to a layer of thorium, one atom thick, on the surface of the tungsten. Fig. 5 shows the volt-ampere characteristic of such a filament in argon at 0.030 mm. pressure. The current rises rapidly with increasing potential up to 22 volts, but with further increase of voltage it falls rapidly to essentially zero at 70 volts. Careful tests have shown that the loss of emission is not due to any chemical attack nor rise of temperature of the filament, but solely to removal of the single layer of thorium atoms by positive ion bombardment. The residual emission at 70 volts represents essentially the emission of a pure tungsten filament. As long as the high voltage is maintained the thorium which is continually diffusing to the surface is removed as fast as it arrives. If the voltage is slowly reduced, the layer reforms, and with it the electron emission returns, as shown by the dotted curve in Fig. 5. The fraction of filament surface covered with thorium at each voltage represents an equilibrium between the rate of gain of thorium by diffusion and the rate of loss by positive-ion bombardment.

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(6) Langmuir, *Phys. Rev.*, *2*, 450, 1913.

(7) Langmuir and Blodgett, *Phys. Rev.*, *22*, 347-56, 1923.

(8) A. W. Hull, *Trans. A.I.E.E.*, *47*, 753-63, 1928 K. H. Kingdon and I. Langmuir, *Phys. Rev.*, *22*, 148-60, 1923.

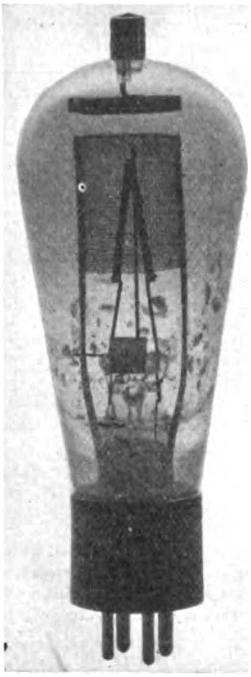

Fig. 6. Thyratron with Barium-coated Nickel Filament. This type of cathode heats quickly, but requires about 60 watts heating energy per ampere average output

Exactly similar behavior, though less regular, may be observed with barium-coated cathodes.(9) In the case of pure tungsten filaments, the loss due to bombardment has been determined by the change in resistance; and the results are in agreement with those for thoriated tungsten. The fact to be emphasized is not that positive-ion bombardment can cause disintegration, which has long been known, nor that the disintegration in thyratrons should be very much greater than in Geissler tubes because of the large currents carried, but that *there exists a voltage below which positive ions cause no disintegration;* and that *this voltage is sufficiently above the ionization potential so that between them is a practical operating range.* The main objective of proper cathode design is to enable the operating voltage drop to be kept within this range.

5. Behavior of Filaments as Cathodes

The thyratron can utilize any type of electron-emitting cathode, *viz.*, pure tungsten, thoriated tungsten, barium-coated, caesium-coated, or mercury. Fig. 6 shows a thyratron with a barium-coated nickel filament as cathode. For small thyratrons the filament may be identical with the filaments used in vacuum tubes. For larger tubes a more massive construction and special means of mechanical support are required. Cathodes of the filament type have the advantage of fairly quick heating, as compared with the type shown in Fig. 7, but are rather inefficient as electron emitters for engineering applications, and are limited in life and subject to accidental failure. At maximum efficiency on sine-wave alternating-current operation they require 30 watts heating energy per average ampere output, and for conservative rating should have about 60 watts per average ampere.

Lest this efficiency seem too conservative, it must be emphasized that *the electron emission to be expected is the same as in vacuum.* The temptation to use the tenfold increase that may be obtained, due to positive-ion bombardment and successive multiplication, by raising the anode-cathode voltage, is responsible for most of the cathode failures of the past. This does not apply to tubes which operate with much higher gas pressure, like the Tungar rectifier. Such pressures,

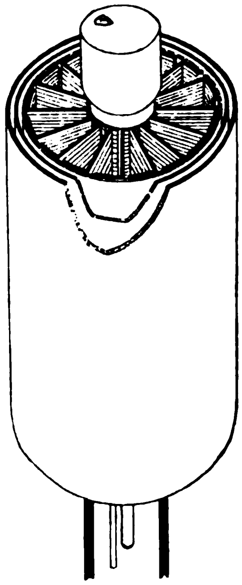

Fig. 7. Multicellular Cathode, Completely Heat-shielded Except for One Open End, from which Electrons Emerge. The heat required, which is furnished by a tungsten filament at the center, is only 1/24 as much as for a filament of the same electron-emitting area

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(9) The term "barium-coated cathode" will be used throughout this article to designate the type of cathode which is usually referred to as "oxide-coated" or "Wehnelt," since recent investigations have shown that the electron emission is not due to alkaline earth oxide but to a monatomic film of alkaline earth metal, particularly barium, bound to the nickel surface by oxygen.

of 1 mm. or more, have a definite protective action, which prevents evaporation of active material, allowing higher operating temperature and considerably increasing the electron-emitting efficiency. A discussion of this "tungar effect," as it may be called, may be found in an earlier paper.[10] A fuller account of this effect, and of the exponential multiplication that may be obtained with high anode voltage, will be published soon, in the *Proc. Nat. Acad. Sci.*, by Dr. Katherine Blodgett. The best pressure for thyratrons is of the order of $\frac{1}{100}$ of the minimum tungar pressure, so that no appreciable help from this protective action is to be expected in thyratrons.

The length of filamentary cathodes for thyratrons has two limitations, which differentiate them from pliotron filaments. The first is that the maximum voltage between the ends should not be greater than the difference between the ionization and disintegration potentials. If it is greater than this, then when the positive end is just able to furnish electrons that can produce ionization, the negative end is so negative with respect to the anode that it suffers disintegration. The second limitation is a functional one. In tubes of the type shown in Fig. 6, the maximum potential difference between the ends of the filament should not exceed the ionization potential of the gas, unless the ends are so shielded from each other that ionization cannot take place between them. Any ions so produced would form sheaths around the grid wires and prevent the grid from controlling the starting of the arc.

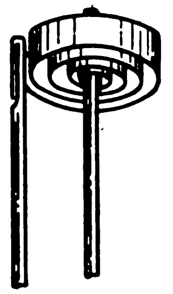

Fig. 8. Filament of Broad Nickel Ribbon, so Mounted That Adjacent Turns Shield Each Other from Heat Loss. This filament requires only one-third as much energy as it would if straight

6. Heat-insulated Cathodes

To increase efficiency and life, advantage may be taken of a fundamental difference between vacuum and gas-filled tubes. The problem of efficiency is to obtain the maximum electron emission with minimum heating power, which means minimum loss of heat by radiation. In vacuum tubes electrons and heat radiation both proceed from the filament in essentially straight lines, so that the two are always proportional, whatever the shape or size of the filament. In gas tubes, on the other hand, the presence of positive ions enables the electrons to turn corners and emerge from narrow crevices, while the heat radiation must still proceed in straight lines. Hence it is possible to shield the cathode from heat loss, except for small openings through which the electrons emerge. Figs. 7 and 8 are examples of such heat-shielding. In Fig. 8, the filament, which is a wide strip of barium-coated nickel, is wound in a spiral so that adjacent turns shield each other from loss of heat. The total heat required is thus reduced to one-third of that required for an unshielded filament like the one in Fig. 6. This gain is accomplished without appreciable increase in the time required for heating. It is practical to increase the saving of heat still further by increasing the width of strip. For example, a ribbon 5 cm. wide, wound in a spiral of 3 mm. pitch, would require only one-twelfth as much heat as a straight filament of equal area. It is evident, also, that the loss, by evaporation, of active electron-emitting material from such a coiled filament would proceed more slowly than from an open cathode, because of the probability that material evaporating from one portion will be caught by another. Hence its life at the same temperature may be expected to be much longer.

Fig. 7 shows a different method of heat shielding which is still more efficient than that shown in Fig. 8, but involves a slight delay, after the beginning of heating, before operating temperature is attained. In this case a large area of electron-emitting metal, consisting of radial vanes coated with activating material, is enclosecd in a cylinder which is completely heat insulated except for one end. Any insulating material may be used, but concentric bright nickel cylinders have been found very satisfactory. Three such cylinders, as shown, the inner one being part of the electron-emitting surface, reduce the heat flow to 3 per cent of that from a black body, or 4 per cent of that from a barium-coated nickel surface. This is so small compared with the loss from the open end that further reduction is hardly worth while.* The total heat loss, including the open end, is one-sixth as much as from a similar area of oxide-coated nickel. The inclusion of the vanes, whose area is three times that of the inner cylinder, makes the total electron-emitting area four times and hence the efficiency 24 times that of a similar cylinder or other coated surface without heat shielding. Assuming the conservative value of 60 watts per ampere average emission for an unshielded filament, this cathode would require only 2.5 watts per ampere. The heat-shielding can be carried much farther than shown in Fig. 7, by decreasing the relative size of the open end. Cathodes have been made with twice the ratio of length to diameter and twice the number of vanes shown, which have an efficiency-factor of 100 compared with a simple filament, or a conservative heat requirement of only 0.6 watts per average ampere of rated output current on alternating-voltage operation. This includes only the heat necessary to maintain the temperature of the cathode when idle, *i.e.* the wasted heat. In addition, there is needed about one watt of useful heat per ampere to liberate the electrons. This requirement appears to be just supplied, sometimes slightly oversupplied, by heat from the arc, mainly condensation of positive ions.

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[10] Hull: "Gas-filled Thermionic Tubes." *Trans. A.I.E.E.*, *47*, 753-63, 1928

*NOTE: I am indebted to Dr. Lewi Tonks of our laboratory for the following theorem for the heat-shielding efficiency of metallic surfaces: Assume k concentric metal surfaces all alike, of relative emissivity e, sufficiently close together so that the difference in radii may be neglected. The heat necessary to maintain the inner surface at constant temperature is $\frac{eE}{2k-1-(k-1)e}$ where E is the energy radiated by a black body of the same size and temperature. When e is small, as in the case of bright metal surfaces, this quantity reduces to $\frac{eE}{2k-1}$. For black surfaces, $e=1$, it becomes simply $\frac{E}{k}$. A full discussion of this subject has recently been published by Skaupy, *Zeit. fur Phys.*, *51*, 388, 1928.

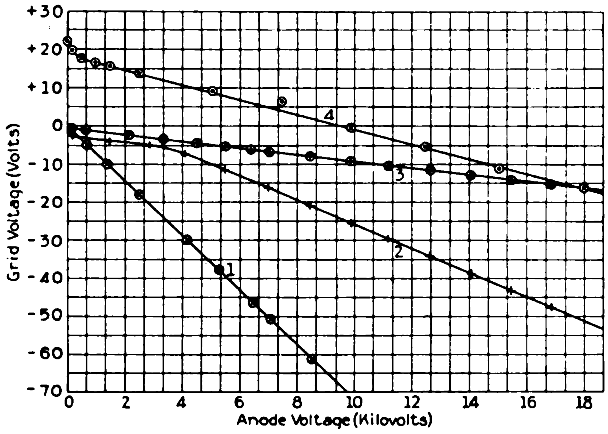

Fig. 9. Control Characteristics of Thyratrons of Types Shown in Figs. 10 to 13, Showing Grid Voltage at which Current Starts, as Function of Anode Voltage. Curves *1*, *2*, *3*, and *4* refer to tubes of Figs. 10, 11, 12, and 13 respectively. Note that the Characteristics *1* and *3* are straight lines, indicating that the grid-control ratio is constant. Characteristic *2* shows a slight deviation from linearity; and Characteristic *4* crosses the axis and becomes positive for low anode voltages

An important advantage of this type of cathode is that the heating element may be insulated from the cathode and may be wound for any desired voltage, *e.g.*, 110 volts. This is important in connection with "inversion," to be described later.

The life of these cathodes can only be estimated at present. Two cathodes of the type shown in Fig. 7 have been on test for nine months, one in continuous operation at full output, the other in intermittent operation. Neither shows any change or sign of aging.

7. Thorium-coated Cathodes

It is obvious from what has been said that any of the types of cathode shown in Figs. 6, 7, and 8 may be made with thorium-coated tungsten or molybdenum instead of barium-coated nickel. The efficiency is in each case approximately the same for the thorium-coated cathode as for the barium-coated. Cathodes of the type of Fig. 7 have been successfully made with thoriated molybdenum. The tungsten heater is preferably on the outside in this case, surrounded in turn by insulation.

Thorium-coated cathodes have the disadvantage, as compared with barium-coated cathodes, of more quickly losing their coating from bombardment in case of improper use (see Section 4); but have a great advantage for thyratrons in regard to the size of grid that is needed, since the grid can be operated at higher temperature without emitting electrons. This requirement is treated in Section 9.

8. Comparison of Grid Function in Thyratron and Pliotron

The grid of a thyratron, when it functions to control the starting of current, behaves exactly as in a pliotron. This is obvious, since, before current starts, there are no ions, and the electric fields in the tube are therefore the same as in a vacuum tube. The criterion for no current is the same as in a pliotron, *viz.*, there will be no current as long as the electric field around the cathode is negative. This field is due to the combined effect of anode voltage (e_p) and grid voltage (e_g), and is a function of

$$e_g + \frac{e_p}{\mu}$$

where μ is defined as the amplification factor in the pliotron. In the same way an amplification factor for the thyratron may be defined as the ratio of anode to grid voltage at which current will just start. It is to be noted that this factor, in the case of the thyratron, is measured at zero current, and is determined by the *largest hole* in the grid (cf. Section 9); while in the pliotron it is measured at average operating current, and is determined by the *average* grid mesh. Moreover, this factor is not connected with amplification in the case of the thyratron, but rather with the value of grid bias at which the tube will start. It seems preferable, therefore, to introduce a new

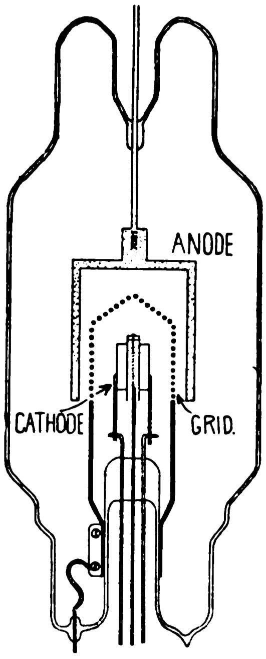

Fig. 10. Completely Shielded Glass Thyratron, with Multicellular Cathode

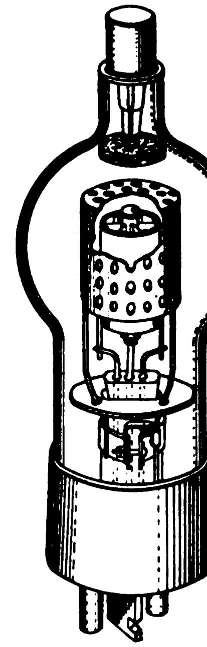

Fig. 11. Partially Shielded Glass Thyratron. This structure allows maximum grid diameter, but is subject to a slight "glass effect"

term, "grid-control ratio," to designate *the ratio of negative grid voltage to anode voltage that will just allow current to start.* This is the inverse of the amplification factor as just defined.

Fig. 9 shows the control characteristic, *i.e.*, the grid voltage at which the thyratron starts, as a function of anode voltage for the different types of thyratrons shown in Figs. 10 to 13. Curve 1 is for a tube similar to that in Fig. 10, with a control ratio of 0.007. The characteristic is a straight line, as it should be, indicating that the grid-control ratio is a constant in this type of thyratron. The same is true of the tube shown in Fig. 12, of which Curve 3 is a characteristic.

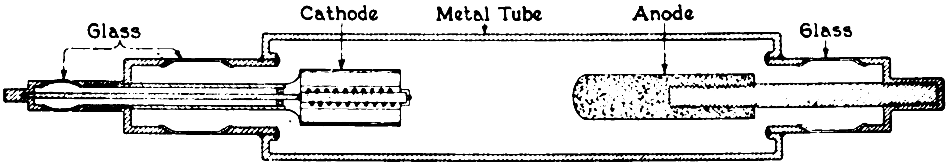

Fig. 12. Metal Thyratron. The metal envelope acts as grid. This tube can carry large currents without danger of grid emission

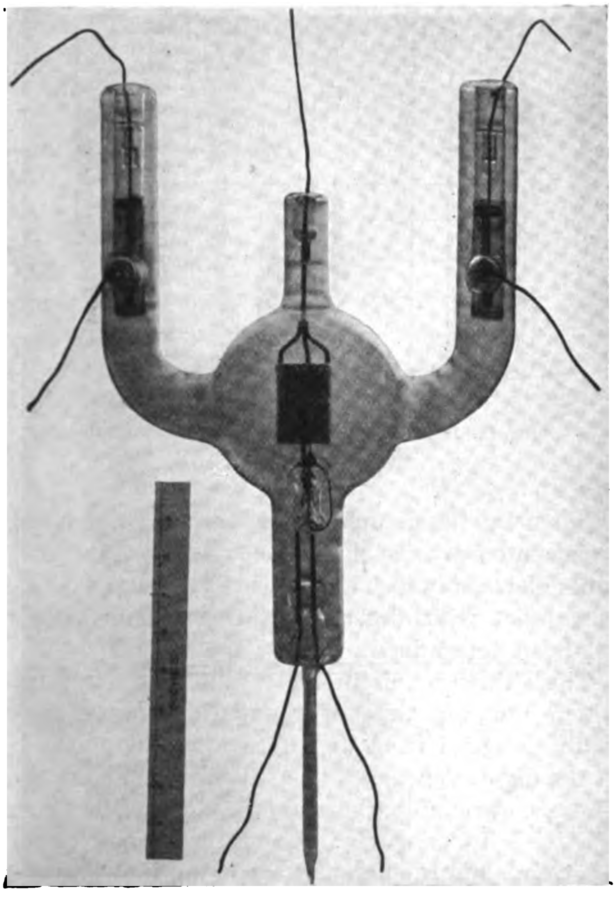

Fig. 13. Multiphase Thyratron. The long glass arms make it possible to protect the anodes from each other. Any number of anodes may be used

In tubes in which the electrostatic field of the glass walls can reach the cathode the grid-control ratio will not be constant, since the glass acts as an additional grid of unknown potential. This is true to a slight extent in the type of tube shown in Fig. 11, where the glass has a grid effect of the second order, comparable per unit potential and per unit area to the anode rather than the grid. Its effect is noticeable only at low anode voltages, but is easily seen in Curve 2, Fig. 9, which is a characteristic of a tube of this type. In tubes of the type shown in Fig. 13, on the other hand, the glass is just as effective as the grid. If the glass is allowed to assume random potential, the behavior of the tube is very erratic. This may be avoided by maintaining a state of ionization in the lower part of the tube, which keeps the glass walls, as Langmuir has shown,(3) slightly negative with respect to the ionized gas. In order to start at ordinary anode voltages the control grid must be a few volts positive, as shown in Curve 4 of Fig. 9.

The best value of grid-control ratio appears to be the smallest value consistent with the following requirement: that the tube shall start, at operating anode voltage, at a grid voltage such that the grid impedance is high, *i.e.*, that the grid does not receive any appreciable electron current from the cathode. The value of this minimum grid voltage is of the order of ½ volt negative. This gives an optimum grid-control ratio of about 100.

As soon as current starts the similarity between pliotron and thyratron ends. The thyratron has no "mutual conductance," *i.e.*, rate of increase of plate current with grid voltage. The current, once it starts, rises abruptly, in a fraction of a microsecond, to its maximum value. This value is limited only by the external load resistance. In the same way "plate impedance" has no meaning in the thyratron, since the plate current, once it starts, is practically independent of plate voltage. For purposes of comparison the thyratron might be said to have infinite mutual conductance and zero plate impedance. Figs. 14 and 15 show these characteristics, plotted to scale, for the 50-watt pliotron, UV-203A, with and without gas, *i.e.*, as thyratron and pliotron respectively.*

9. Essential Requirements of Thyratron Grids

The requirements of thyratron grids differ in several respects from those of pliotron grids, and it is desirable to state these requirements briefly before describing the types of grid that have been found practical.

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*NOTE: In this treatment and in all that follows, it is assumed that the electron emission from the cathode is sufficient for the maximum instantaneous demand, so that the plate current is never limited by cathode emission. In pliotrons this condition is satisfied in the case of small amplifiers, but is seldom realized in power tubes. In thyratrons it is essential for the life of the cathode, as explained in Section 4.

They can, perhaps, be most simply pictured by pointing out the difficulties which are encountered on attempting to use pliotrons of standard types as thyratrons.

The most serious difficulty, especially with the smaller pliotrons, is *incompleteness* of the grids. They are too short to shield the whole filament. This results in a small uncontrolled emission, so small that it is unobjectionable in a pliotron, but in a thyratron it determines the grid-control ratio, giving a ratio so large, often greater than unity, that the tubes are not very useful. The same effect is produced, though to a less extent, by non-uniformity in the grid. *The largest hole determines the grid-control ratio.* The reason for this will be obvious from the considerations that have been given in Sections 3 and 8.

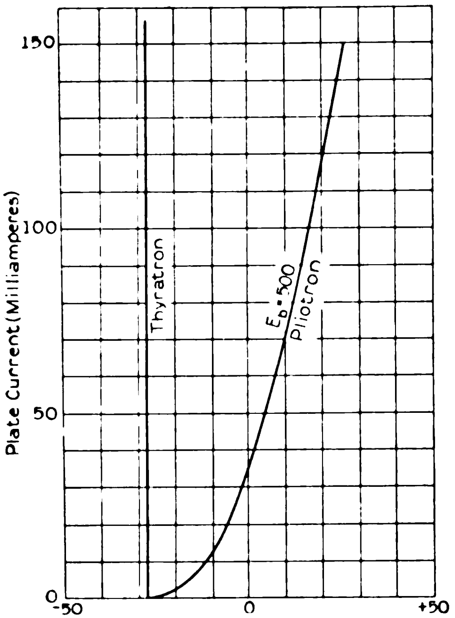

Fig. 14. Plate Current vs. Grid Voltage in a Pliotron UV-203A, and a Thyratron which Was Made from the Same Tube by the Addition of 0.005 Mm. Mercury Vapor

With the larger tubes, difficulty is encountered with filaments rather than grids. Nearly all of them are unsuitable for thyratrons because of the *high filament voltage*. As pointed out in Section 5, if this voltage is above the ionization potential of the gas, a discharge can pass between the ends of the filament, thus producing ions which sheathe the grid and make its negative potential ineffective.

Pliotrons with barium-coated cathodes are an exception. They do not, in general, have such high filament voltage. But these suffer from a much more serious defect, which is present in many of the other tubes, and is the most serious grid problem yet encountered. This is grid emission. *The grid must not emit electrons.* It is obvious that such electrons are equivalent, as far as "starting" the tube is concerned, to an equal number from the cathode, and if sufficient in number to cause starting, no negative voltage can prevent it. The allowable emission depends upon anode voltage and grid design, and is difficult to specify. A few microamperes is generally sufficient to spoil the control at 110 volts. This factor of grid emission dictates the size of grid in thyratrons of the types shown in Figs. 6, 10, and 11, which have barium-coated cathodes. The grid frequently operates a long time before it becomes coated with a barium film of optimum electron emissivity, but it is believed that all grids eventually arrive at this stage. Experience thus far indicates that the maximum safe rating for a tube like that in Fig. 11 is $\frac{1}{10}$ amp. per sq. cm. of useful grid area. In tubes like that in Fig. 6 the limiting current is still lower, because of the greater heat radiated by the filament. The limiting value is much higher in tubes with thorium-coated cathodes, and in tubes like that in Fig. 12 the grid of which is a cylinder in contact with the air, but these limits have not yet been determined.

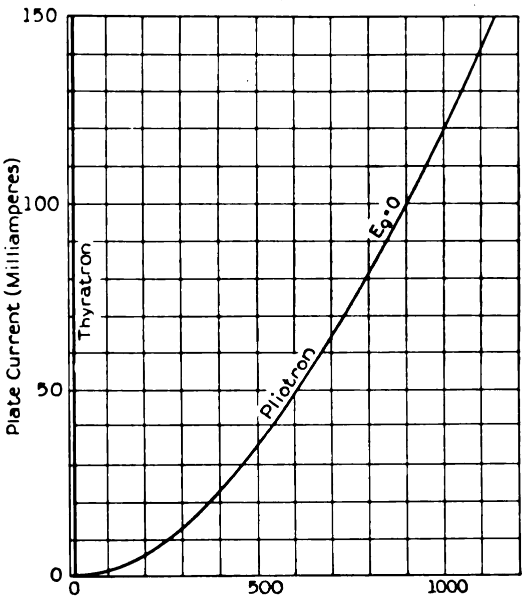

Fig. 15. Plate Current vs. Plate Voltage for the Tubes Referred to in Fig. 14

These three requirements are illustrated in Fig. 16, which shows a tube of conventional type that is badly designed from the thyratron standpoint. Part of the filament projects beyond the grid and is therefore uncontrollable; the grid is so close to the filament that it is in danger of becoming hot and emitting electrons; and the filament is so long that its voltage is likely to cause ionization.

This example is given to emphasize the differences between pliotron requirements and those of thyratrons. It is not intended to show that a useful thyratron could not be made of this general form, but rather that the features which constitute its merit as a pliotron, *viz.*, extended filament and close grid-filament spacing, are of no advantage in a thyratron and constitute a menace. A possible exception may be found in the case of thyratrons for very high frequency operation, where close spacing may be necessary in order to reduce the de-ionization time to a minimum (see Section 10).

The foregoing treatment refers to grids that surround the cathode. If the grid surrounds the anode, as in Fig. 13, it is free from some of these limitations. This has the following consequences: it makes possible the use of several anodes in the same tube; ionization due to high filament voltage does not affect the grid; it is possible to use caesium-coated filaments, or caesium as the conducting gas, where the ions produced by contact of caesium vapor with the hot cathode would seriously interfere with grid function if the grid surrounded the cathode; the grid is less likely to become coated with electron-emitting material such as barium, hence larger currents can be controlled by a grid of the same size; tubes of this type show the shortest de-ionization time of any that have been tested.

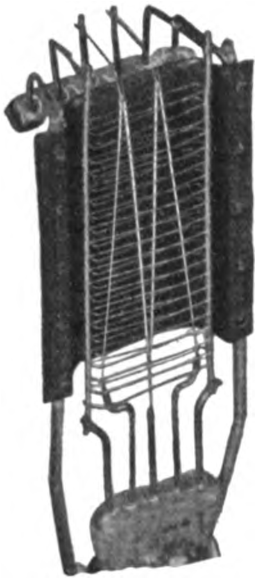

Fig. 16. Example of Incorrect Thyratron Structure. Its faults are: poor control ratio, because of short grid; grid emission because of closeness of grid to filament; and ionization due to high filament voltage

10. Gas

The gas problem in a thyratron consists of correct pressure, purity, and constancy.

The best range of *gas pressure* in a thyratron is between 1 and 50 microns for mercury vapor; for other gases, especially helium, it is somewhat higher. This is very low compared with tubes of the type of the Tungar rectifier, which operate best with about 5 cm. pressure. The value of the high pressure in the Tungar tube is that it prevents evaporation of thorium or other active material from the cathode, making it possible to operate at a higher temperature, with an electron-emitting efficiency about ten times that in vacuum. In the thyratron it is necessary to forego this advantage, and seek increased efficiency in other ways. The evidence available indicates that the protective action at thyratron pressures is negligible, and that the electron emission per unit area is the same as in vacuum.

The upper limit of pressure for a thyratron is determined by the rate of diffusion of positive ions and the glow potential; the lower limit by the limitation of current density that results from a scarcity of positive ions. The practical lower limit under most conditions is about 1 micron, the upper limit at high voltage about 5 microns, due to glow discharge. A glow discharge between grid and anode, besides disintegrating the grid and using up the gas, will obviously sheathe the grid with positive ions and render it powerless. For low voltages, at 60 cycles, the upper limit is about 100 microns for thyratrons of the type shown in Fig. 11.

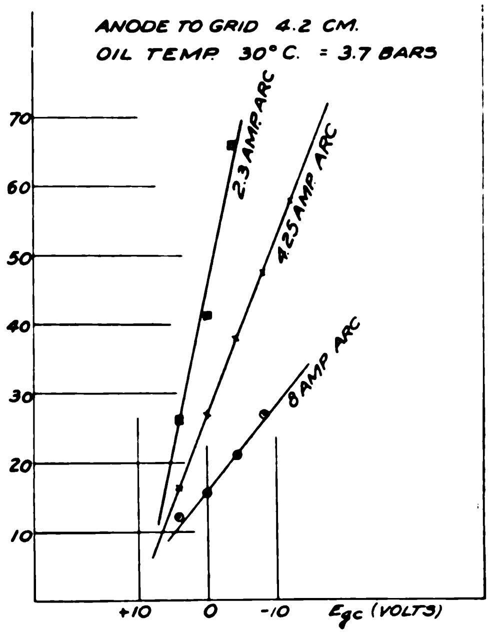

Fig. 17. De-ionization Time in Microseconds as Function of Grid Voltage

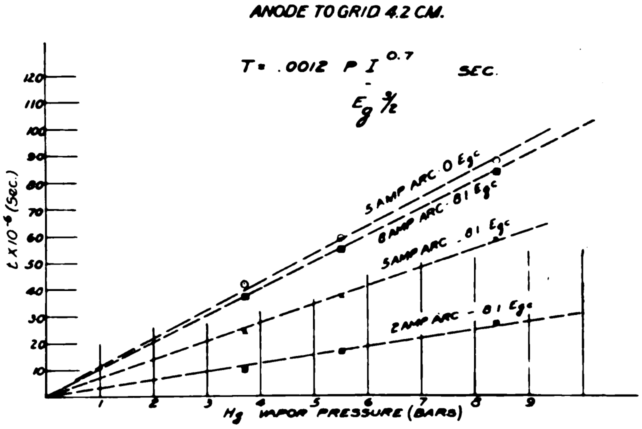

Fig. 18. Variation of De-ionization Time with Gas Pressure

The time of diffusion, or *de-ionization time*, is of great importance. The function of the grid is to control starting, and the possibility of this control depends upon the absence of positive ions before starting. If the arc is to be started but once, rapid diffusion is unimportant and the gas pressure may be as high as is consistent with glow discharge or other limitations. For repeated starting, it is necessary that the ions should disappear during the interval between the removal and return of positive anode voltage. This is a half cycle in the case of alternating anode voltage. With direct-current voltage, when the anode is made negative by means of a condenser discharge, the interval depends on the values of capacity and resistance in this circuit. The time required for the ions to disappear is a function of gas pressure, current, distance, and voltage of the grid. F. R. Elder has measured this time in a tube similar to that in Fig. 13, with the results shown in Figs. 17 to 19. The time varies directly as the pressure, inversely as the distance between grid and anode, as the inverse 3/2 power of the grid potential with respect to the surrounding space, and as the 0.7 power of the current. It is expressed empirically by the equation:

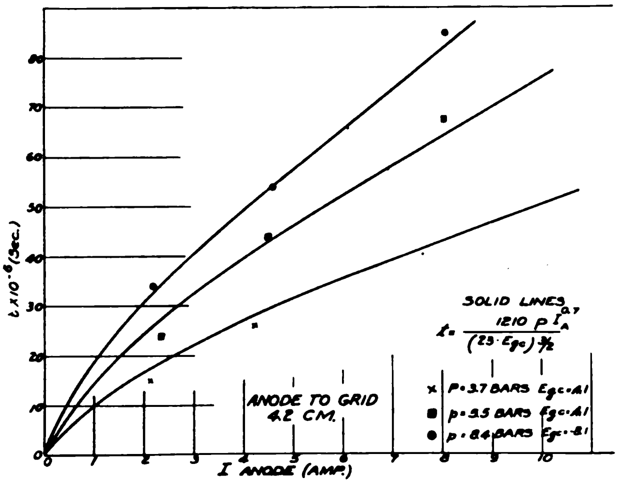

Fig. 19. De-ionization Time as Function of Arc Current

$$t = \frac{0.0012\, pI^{0.7}}{e_g^{3/2}\, x} \text{ sec.}$$

where p is the pressure in baryes, I the arc current, x the distance between grid and anode, and e_g the grid potential with respect to the surrounding space.

Thus at a pressure of 5 baryes and an arc current of 10 amperes, a grid 4 cm. from the anode at 20 volts negative potential would have a de-ionization time of 80 microseconds.

Purity of the gas appears to be essential. It is possible that certain impurities can be tolerated, which do not impair the electron emission, as, for example, carbon monoxide and hydrogen in the case of barium-coated cathodes. The data available indicate, however, that these gases increase the arc-drop, often beyond the disintegrating value, so that it is doubtful if their presence is ever desirable in a finished tube. The degree of exhaust, before the introduction of the essential gas, should in general be as good as that of a high vacuum tube; in some cases much better, as, for example where it is impractical to use a "getter." A typical obituary of a poorly exhausted thyratron is: Gradual evolution of gas, which poisoned the cathode; very high arc drop, due to insufficient emission, which further de-activated the cathode by positive ion bombardment; sputtering and local melting of cathode; large gas evolution; loss of grid control. With low operating voltage or small currents, the illness is more prolonged, and the poisoned cathode may operate with high-voltage drop for a considerable time, generally between 20 and 200 hr., until disintegration removes its active surface.

Gases rapidly disappear or "clean up," as is well known, in cold-cathode glow discharges, and in most of the low-pressure hot-cathode discharges that have been studied. The gas that has disappeared is found in the cathode and walls of the tube. The evidence available indicates that *monatomic gases will "clean up" very little if at all in thyratrons*, provided the voltage drop is kept below the "disintegration" value. This is equivalent to saying that the tube is a correctly designed thyratron and used as such, which means proper exhaust, proper design for the load it is to carry, and proper operation. A thyratron with permanent gas filling may be ruined, however, by a few moments of faulty operation, as, for example, when full load is demanded before the cathode attains normal operating temperature.

Mercury vapor is free from this hazard, but has the alternative requirement of a certain degree of *temperature control*. The best temperature for most purposes is about 40 deg. C. which gives a pressure of approximtely 5 microns, and the practical operating limits are between 25 and 60 deg. C. This temperature need be maintained only at the extreme bottom portion of the tube, which contains the single drop of liquid mercury—a cubic millimeter is sufficient for a tube of moderate size. The temperature of the remainder of the tube may be anything that the glass or metal of the tube will stand. The problem is therefore much simpler than with the mercury cathode, where a large amount of mercury is vaporized, which condenses on the walls, delivering to them approximately three watts⁽¹⁰⁾ of heat per ampere of

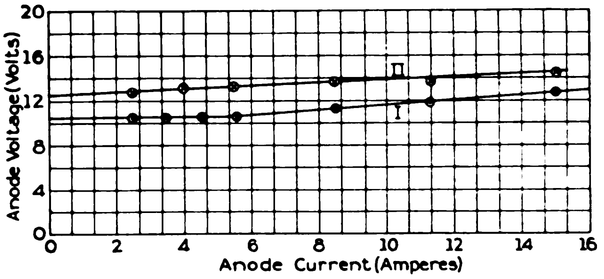

Fig. 20. Plate Characteristic of Thyratrons Shown in Figs. 10 and 11. Note the low internal voltage drop, which is nearly independent of current. The impendance is essentially zero

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(10) K. T. Compton, *Trans. A.I.E.E.*, 47, 9, 1928.

arc current. This heat, plus an equal or greater amount received from the arc stream, must be removed in order to maintain the constant vapor pressure. In the hot-cathode thyratron the single drop of mercury may be in a place that receives no heat, except by conduction from its surroundings.

11. Typical Tubes and their Characteristics

Figs. 6, 10, 11, 12, and 13 show different types of thyratron structure that have been found satisfactory.

Fig. 6 is a filament tube, which is useful where low output and moderate life suffice, as in laboratory measurements of peak voltage and the timing of operations. It differs from a pliotron by its large grid and small anode. The large grid is essential when a barium-coated cathode is used, in order to keep the grid temperature below the electron-emitting point. It is of no disadvantage with any type of cathode, at least for most purposes, since "impedance" due to electron space charge, which dictates the close spacing in pliotrons, is absent. For high-frequency operation it may be desirable to use closer spacings, in order to decrease the de-ionization time. The anode might preferably surround the grid, but in so doing would decrease the possible grid size and hence the possible current capacity for a given bulb size.

Figs. 10 and 11 show typical thyratrons with shielded cathodes. In Fig. 10 the anode completely surrounds the grid and cathode. This gives ideal control characteristics, and the short diffusion distance between grid and anode favors de-ionization and allows a compensating increase in vapor pressure. This tube operates satisfactorily at 110 volts and 60 cycles at vapor pressures corresponding to 100 deg. C., as compared to a limiting value between 60 and 70 deg. for the tube shown in Fig. 11. For high-voltage operation, of the order of 10,000 volts, the limiting temperature is about 50 deg. for both types, due to glow discharge, but this value may be raised, if required, by better shielding. The disadvantage of the completely-enclosing anode is that a larger-neck bulb is required for the same current capacity when barium-coated cathodes are used, since grid emission is the limiting factor.

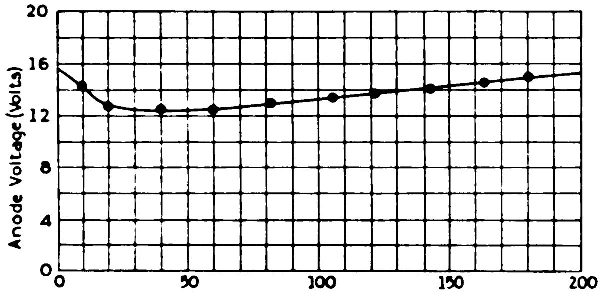

Fig. 21. Plate Characteristic of Thyratron Shown in Fig. 12

Tubes like those in Figs. 10 and 11 with grids 6 cm. in diameter, operate satisfactorily at 5 amp. average output. Their control characteristics are shown in Fig. 9, Curves 1 and 2, and their plate characteristics in Fig. 20.

Fig. 12 shows a different type of control electrode, consisting of a metal cylinder surrounding the space between anode and cathode. By making this cylinder part of the tube envelope, as in Fig. 12, it is possible to keep it cool and thus avoid electron emission from it, even with very large currents. The tube shown has a diameter of 10 cm. and operates satisfactorily with an output of 100 amp. average current. Its control characteristic is shown in Curve 3, Fig. 9, and its plate volt-ampere characteristic in Fig. 21. The cathode is of the multicellular shielded type shown in Fig. 7, barium coated, and requires 300 watts.

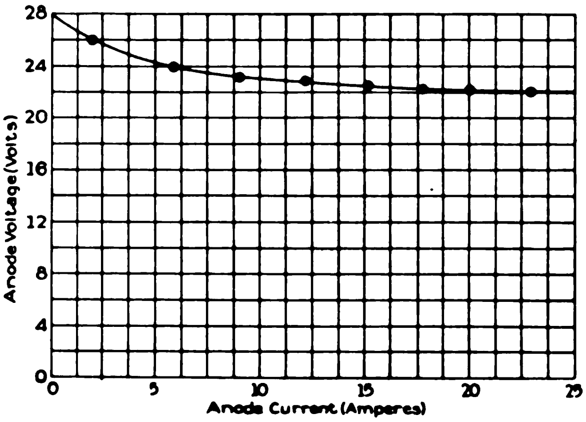

Fig. 22. Plate Characteristic of Thyratron Shown in Fig. 13

Fig. 13 shows a construction which allows multiphase operation in a single tube. It is similar to that in Fig. 3 except for the cathode. The controlling grids surround the anodes, which are sufficiently far apart that the current to one, with its attendant ionization, does not affect the others. In order to maintain at constant potential the glass arms, which act as part of the grids, a continuous supply of ions is produced by a small current to an extra anode, or pair of anodes. The constancy of glass potential thus attained is revealed by the smoothness of the control characteristic, shown in Fig. 9, Curve 4. Its volt-ampere characteristic is shown in Fig. 22. The voltage drop of 22 to 28 volts is higher than in the other types, corresponding to the greater arc length. This high value does not mean disintegration in this case, since the ions from the high-voltage region near the anode lose their energy before reaching the cathode. The tube shown is rated at 25 amp. average output per anode.

(To be continued)

Economical Operation of the 3000-volt Direct-current Electrification of the Paulista Railway

By GUY BELLOWS
Railway Engineering Department, General Electric Company

Descriptions of the initially electrified section of this Brazilian railway, and of the later extensions of the electrification, have appeared in our issues of July, 1921, May, 1924, and May, 1927. Comparative figures of operating costs for steam and electric operation under the conditions of 1923-1925 were presented in the December, 1927, issue. The latest operating statistics, made available through the courtesy of the Railway Company, are furnished in the following article.—EDITOR

WITH the close of the year 1928, the Cia. Paulista de Estradas de Ferro completed the electrification of its broad-gauge main line between Jundiahy and Rincao (Brazil, S. A.), totaling 286 km. (178 miles). The electrification of this railway, which was begun in 1920 by an initial step of 44 km. (27 miles) of double track, has progressed in three extensions in stages of 50, 40, and 152 km. (31, 25, and 94 miles respectively).

A schematic layout of the electrification is shown in Fig. 1. Serving this electrified zone there are eight substations having a combined total normal capacity of 22,500 kw. with a five-minute rating of 67,500 kw. The capacities of the individual substations are as given in Table I.

The first three stations, *viz.*, Louveira, Reboucas, and Cordeiro, are manually operated. The remaining stations are fully automatic, requiring only an attendant for regular inspection and maintenance, or in case of lockout of a station.

From the beginning of electric service on the initial zone in 1921, the saving in operating cost over steam operation has been remarkable and is doubtless showing the best economy over steam operation of any electrification in existence today.

The detailed comparative costs of electric and steam operation for the year 1927 are given in Table II. This table shows clearly the savings obtained.

The electric operation includes all of the section electrified and in operation in 1927 and the steam operation covers all of the remaining broad-gauge lines not electrified in 1927. The cost of electric operation in per cent of steam costs on the ton-kilometer basis for 1927 was 22.1 per cent, or the saving in per cent of steam costs was 77.9 per cent.

Quite the largest factor in the economy of the electrification is the cost of electrical energy versus fuel. The saving with electric power represents 85.6 per cent of the cost of fuel. The cost of fuel is approximately

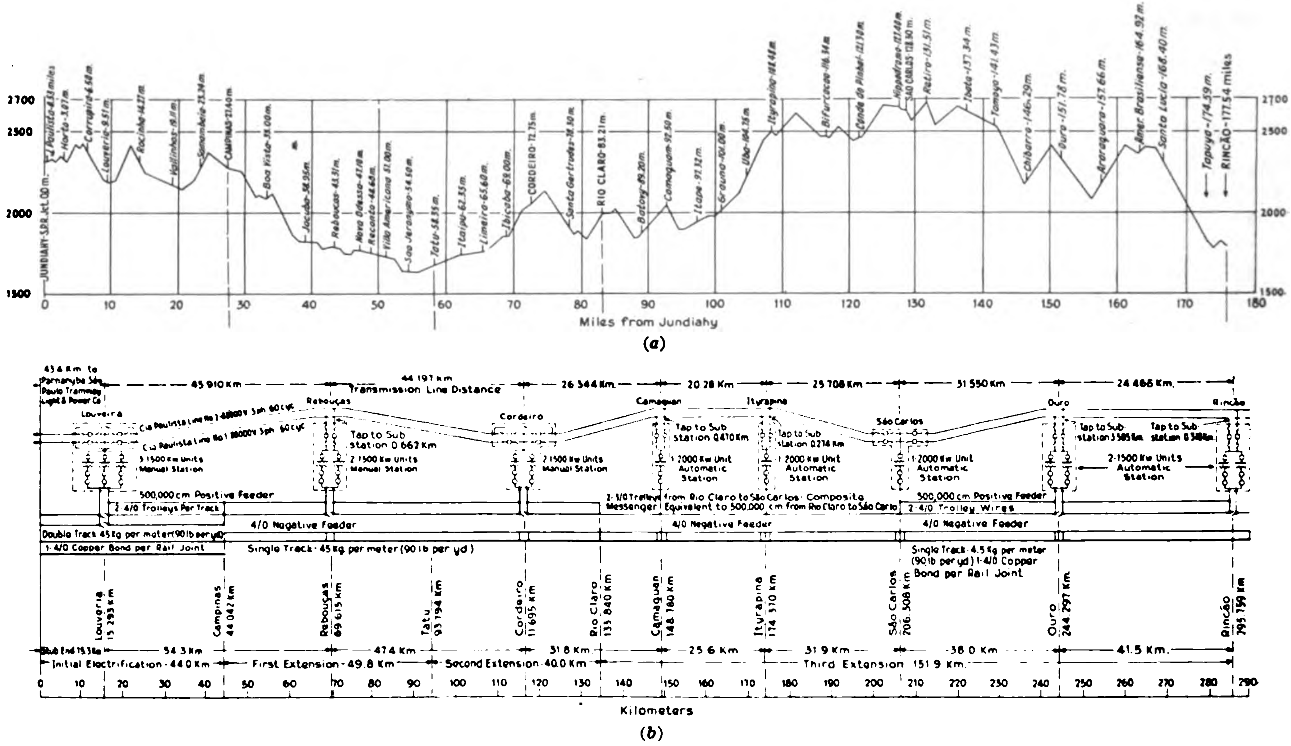
2700
2500
2000
1500
JUNDIAHY-S.P.R. Jct. 0.0 m.
J. Paulista-4.33 miles
Horto-3.07 m.
Corrupira-6.58 m.
Louveira-9.51 m.
Rocinha-14.27 m.
Vallinhos-19.11 m.
Samambaia-23.34 m.
CAMPINAS-27.40 m.
Boa Vista-33.00 m.
Jacuba-38.95 m.
Reboucas-43.51 m.
Nova Odessa-47.10 m.
Recanto-48.65 m.
Villa Americana-51.00 m.
Sao Jeronymo-54.50 m.
Tatu-58.35 m.
Itaipu-62.35 m.
Limeira-65.60 m.
Ibicaba-69.00 m.
CORDEIRO-72.75 m.
Santa Gertrudes-78.30 m.
RIO CLARO-83.21 m.
Batovy-89.20 m.
Camaquam-92.50 m.
Itape-97.32 m.
Grauna-101.00 m.
Ubo-104.75 m.
Ityrapina-108.48 m.
Bifurcacao-116.34 m.
Conde do Pinhal-121.38 m.
Hippodromo-127.48 m.
SAO CARLOS-128.30 m.
Retiro-131.51 m.
Ibate-137.34 m.
Tamoyo-141.43 m.
Chibarro-146.29 m.
Ouro-151.78 m.
Araraquara-157.66 m.
Amer. Brasiliense-164.92 m.
Santa Lucia-168.40 m.
Tapuya-174.59 m.
RINCÃO-177.54 miles
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Miles from Jundiahy
(a)
43.4 Km to Parnahyba São Paulo Tramway Light & Power Co.
45.910 Km
44.197 Km
Transmission Line Distance
26.344 Km.
20.28 Km
25.708 Km
31.550 Km
24.466 Km.
Louveira
Rebouças
Cordeiro
Camaquan
Ityrapina
São Carlos
Ouro
Rincão
Cia Paulista Line No 2-88000 V 3ph 60 cyc
Cia Paulista Line No 1 88000 V 3ph 60 cyc
Tap to Sub station 0.662 Km
Tap to Sub station 0.410 Km
Tap to Sub station 0.214 Km
Tap to Sub station 3.585 Km
Tap to Sub station 0.318 Km
3-1500 Kw Units Manual Station
2-1500 Kw Units Manual Station
2-1500 Kw Units Manual Station
1-2000 Kw Unit Automatic Station
1-2000 Kw Unit Automatic Station
1-2000 Kw Unit Automatic Station
2-1500 Kw Units Automatic Station
500,000 cm Positive Feeder
2-4/0 Trolleys Per Track
2-1/0 Trolley from Rio Claro to São Carlos-Composite Messenger Equivalent to 500,000 cm from Rio Claro to São Carlos
500,000 cm Positive Feeder
2-4/0 Trolley Wires
4/0 Negative Feeder
4/0 Negative Feeder
4/0 Negative Feeder
Double Track 45 Kg per meter (90 lb per yd)
1-4/0 Copper Bond per Rail Joint
Single Track-45 Kg per meter (90 lb per yd)
Single Track-4.5 Kg per meter (90 lb per yd) 1-4/0 Copper Bond per Rail Joint
Louveira 15.293 Km
Campinas 44.042 Km
Rebouças 69.615 Km
Tatu 93.794 Km
Cordeiro 11.695 Km
Rio Claro 133.840 Km
Camaquan 148.180 Km
Iturapina 174.370 Km
São Carlos 206.308 Km
Ouro 244.297 Km
Rincão 295.159 Km
Sub End 15.3 Km
54.3 Km
47.4 Km
31.8 Km
25.6 Km
31.9 Km
38.0 Km
41.5 Km.
Initial Electrification-44.0 Km
First Extension-49.8 Km
Second Extension-40.0 Km
Third Extension 151.9 Km.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
Kilometers
(b)

Fig. 1. (*a*) Profile of the Electrified Section of the Paulista Railway, and (*b*) Schematic Plan of the Substations and Distribution Systems

58.8 per cent of the total steam operating expenses and therefore the saving on the total steam costs is approximately 50.4 per cent. This very clearly brings out the importance of the fuel situation in operating this railway by steam. Wood and coal have been used in varying quantities from year to year, the relative amounts being influenced by the changing price of coal which must be imported. Fig. 6 shows a comparison of the cost of coal and wood on the tender of the locomotive over a period of 15 years. The cost of wood is given at the equivalent of one metric ton of coal, being equal to 8.5 cubic meters of wood. The cost of electric power is also shown on this curve on the basis of 6.5 lb. (3.0 kg. approx.)

TABLE I

Substation	No. of Units	Normal Rating in Kw.	300 Per Cent Load for 5 Min. in Kw.
Louveira	3	4,500	13,500
Reboucas	2	3,000	9,000
Cordeiro	2	3,000	9,000
Camaquan	1	2,000	6,000
Ityrapina	1	2,000	6,000
São Carlos	1	2,000	6,000
Ouro	2	3,000	9,000
Rincao	2	3,000	9,000
	14	22,500	67,500

TABLE III

Year	STEAM COST		ELECTRIC COST		Cost of Electric Operation in Per Cent of Steam Operation
	Per Train-km. (Milreis)	Per Train-mile (U.S. Cts.)	Per Train-km. (Milreis)	Per Train-mile (U.S. Cts.)	
1922	3$647	69.0	1$198	22.6	32.8
1923	4$299	81.5	1$405	26.6	32.7
1924	4$101	77.8	1$975	37.4	48.1
1925	4$304	81.5	1$770	33.5	41.1
1926	3$780	71.6	1$647	31.2	43.5
1927	3$823	72.4	1$575	29.8	41.2

NOTE: The costs in U. S. cents were deduced on the basis of exchange of 8$500 equal to one U. S. dollar.

TABLE II

COMPARATIVE OPERATING COSTS, PAULISTA RAILWAYS, 1927

(The basis of exchange used in this comparison was 8$500 equal to one U.S. dollar or one milreis equal to 11.76 U.S. cents.)

	STEAM			ELECTRIC			STEAM			ELECTRIC		
General												
Total ton-miles, gross							406,004,849			531,470,124		
Total train-miles	1,650,273			1,160,531								
Ave. weight of train, trailing tons (2000 lb.)	246			458			246			458		
Tons of coal	780,002						780,002					
Cubic meters of wood	625,999						625,999					
Kw-hr. electrical energy				26,998,593						26,998,593		
Cost of coal per ton	$8.324						$8.324					
Cost of wood per cu. m.	1.134						1.134					
Cost of power per kw-hr.				$0.0049						$0.0049		
Watthours per ton-mile										50.8		
	PER TRAIN-MILE (U. S. Cents)			PER TRAIN-MILE (U. S. Cents)			PER 1000 GROSS TON-MILES (U. S. Cents)			PER 1000 GROSS TON-MILES (U. S. Cents)		
	Mat'l	Labor	Total	Mat'l	Labor	Total	Mat'l	Labor	Total	Mat'l	Labor	Total
Conducting Trains												
Crews, cleaners and enginehouse expense		18.57	18.57		8.45	8.45		75.50	75.50		18.46	18.46
Fuel, coal and wood	42.57		42.57				173.24		173.24			
Electric power				11.45		11.45				25.03		25.03
Lubricants	1.23		1.23	0.47		0.47	5.03		5.03	1.02		1.02
Waste and miscellaneous	3.48		3.48	2.29		2.29	14.15		14.15	5.02		5.02
Total	47.28	18.57	65.85	14.21	8.45	22.66	192.42	75.50	267.92	31.07	18.46	49.53
Locomotive repairs	2.43	4.15	6.58	0.91	1.15	2.06	9.88	16.84	26.72	1.98	2.55	4.53
Substations				0.21	2.37	2.58				0.46	5.18	5.64
Trolley lines				0.15	1.12	1.27				0.37	2.43	2.80
Power transmission lines				0.15	1.10	1.25				0.32	2.39	2.71
Total	2.43	4.15	6.58	1.42	5.74	7.16	9.88	16.84	26.72	3.13	12.55	15.68
GRAND TOTAL	49.71	22.72	72.43	15.63	14.19	29.82	202.30	92.34	294.64	34.20	31.01	65.21
Saving in favor of Electric Traction						42.61						229.43
Saving in per cent of Steam Costs						58.8						77.9
Cost of Electric in per cent of Steam Costs						*41.2						* 22.1
Ratio of Train Weights, Electric to Steam						1.86						1.86

* NOTE: The difference in costs on the train-mile and ton-mile basis is explained by the increase in the tonnage of the electric trains.

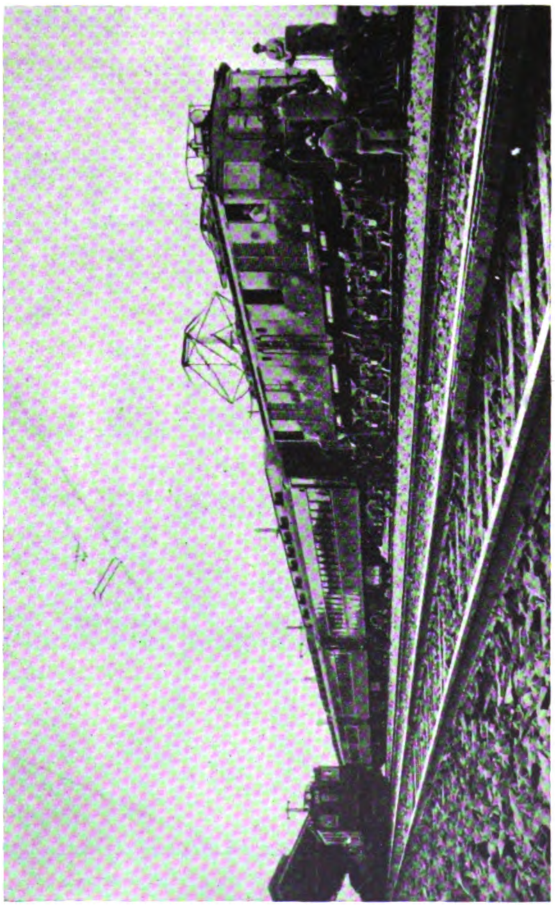

Fig. 2. Passenger Locomotive, 147 Tons, 3000 Volts, and 572-metric-ton Train of New All-steel Vestibuled Coaches

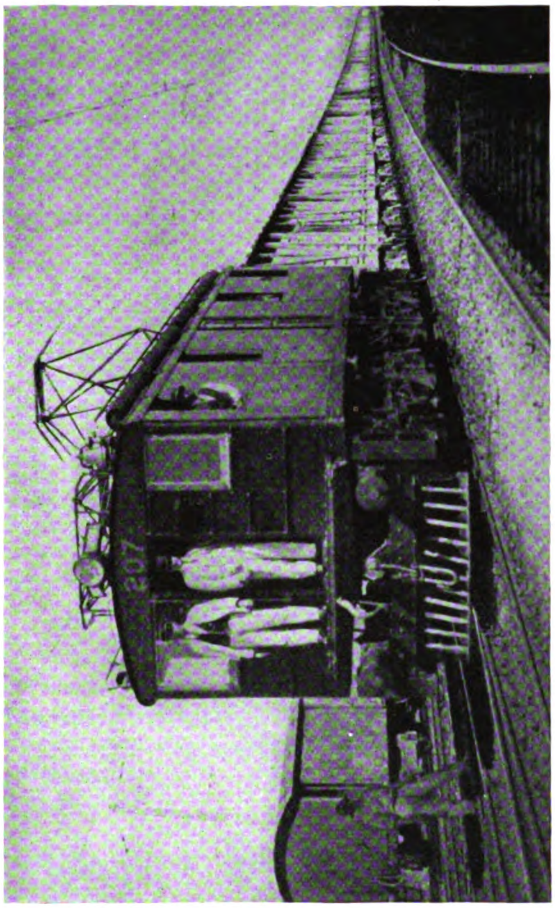

Fig. 3. Freight Locomotive and Stock Train on the Paulista Electrification

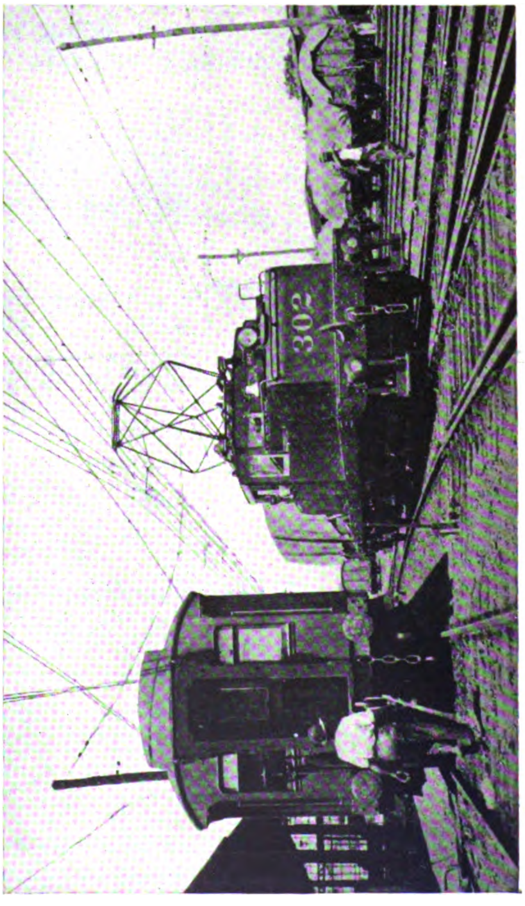

Fig. 4. Switching Locomotive Operating in the Campinas Yards

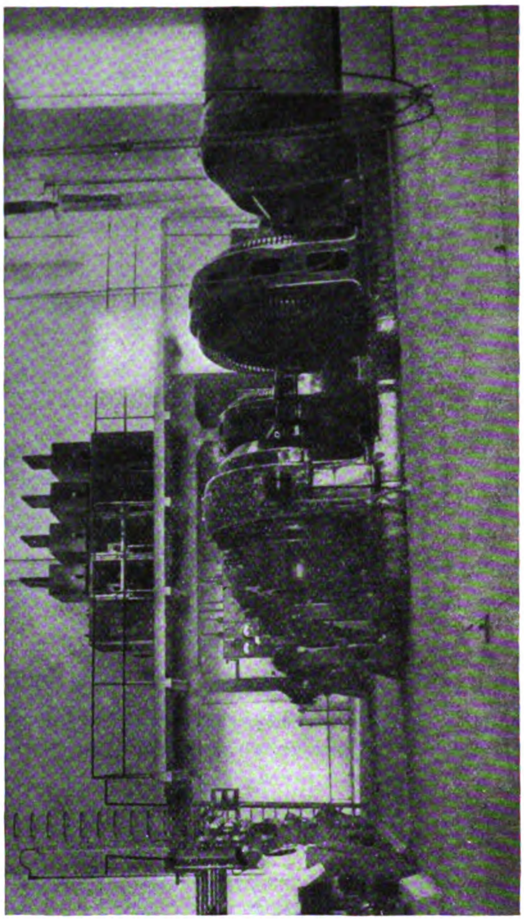

Fig. 5. Interior of the Reboucas Substation, showing the Two Motor-generator Sets

of coal equal to a kilowatt-hour purchased at the high-tension bus. The relation of the cost of coal and wood to the cost of electric power shows again the saving to be made in the fuel item.

A comparison of the steam and electric operation from 1922 to 1927 inclusive is shown in Table III.

During the year 1927 the electric locomotives operated a total of 2,004,284 km., including passenger, freight, and switching service. The total cost of electric locomotive maintenance, running maintenance, and repairs, was 477:065$760 or equal to 0$238 per locomotive-kilometer (4.5 U. S. cents per locomotive-mile—based on 8$500 equal to one U. S. dollar).

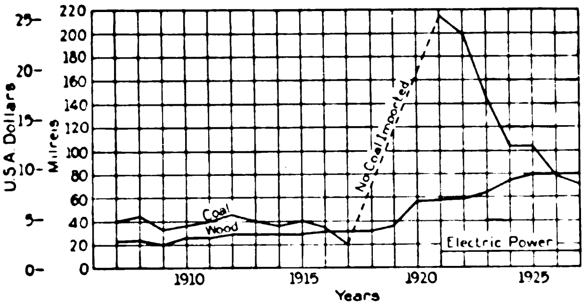

Fig. 6. Curves Showing the Comparative Cost of Coal and Wood on Locomotive Tender and Cost of Electric Power; All Reduced to the Coal-equivalent Basis

The average adhesive weight of the locomotives in service in 1927 was 83.8 metric tons, and hence the maintenance cost for the purpose of comparison would be 0$284 per 100 metric tons adhesive weight (4.87 U. S. cents per 100 tons of 2000 lb.). This maintenance cost is a very commendable showing and the more so when one considers that approxmately 50 per cent of the locomotives have now been in service over seven years. The maintenance figures do not include any depreciation charges, or interest on investment.

The Cia. Paulista de Estradas de Ferro has enjoyed a splendid increase in traffic in both passenger and freight service, requiring the addition of new passenger trains and heavier equipment. The increase in freight traffic has been taken care of by the increased capacity of the electric freight locomotives over steam freight locomotives, and hence has not necessarily increased the number of freight trains.

In order to take care of the increased passenger traffic, the Cia. Paulista has put in service new all-steel vestibuled trains weighing approximately 600 metric tons. To handle these heavier trains five additional passenger locomotives are needed. Three of them were placed in service in 1928 and the remaining two will enter service early this year. They are the largest locomotives of the 3000-volt direct-current type used outside of the United States, and are capable of hauling a 600-metric-ton (662-ton, 2000 lb.) trailing train over the entire profile of the present electrified section between Jundiahy and Rincao. One of these locomotives with the new steel passenger train equipment is shown in Fig. 2. The principal data of the locomotives are given in Table IV.

TABLE IV

Type	1−C+C−1	Weight of electrical equipt. (metric tons)	53.0 (117,000 lb.)
Total weight (metric tons)	133.3 (294,000 lb.)	Weight of mechanical equipt. (metric tons)	76.2 (168,000 lb.)
Total adhesive weight (metric tons)	107.5 (237,000 lb.)	Weight of braking equipt. (metric tons)	4.1 (9,000 lb.)

	Tractive Effort	Speed	Tractive Hp.
ONE-HOUR BLOWN RATING AT 3000 VOLTS			
Full field, FS-1	13,890 kg. (30,627 lb.)	53.6 k.p.h. (33.3 m.p.h.)	2,725
Shunted field, FS-2	12,000 kg. (26,460 lb.)	62.3 k.p.h. (38.7 m.p.h.)	2,730
Shunted field, FS-3	10,530 kg. (23,219 lb.)	71.2 k.p.h. (44.2 m.p.h.)	2,735
CONTINUOUS RATING AT 3000 VOLTS			
Full field, FS-1	11,760 kg. (25,931 lb.)	56.0 k.p.h. (34.8 m.p.h.)	2,405
Shunted field, FS-2	10,180 kg. (22,447 lb.)	64.8 k.p.h. (40.2 m.p.h.)	2,410
Shunted field, FS-3	8,850 kg. (19,514 lb.)	74.8 k.p.h. (46.5 m.p.h.)	2,415

The motors are force-ventilated and of the standard box-frame type, axle-hung and supported on the transom through a spring-nose support. The drive is through twin cushion-type gears.

The control is of the electro-pneumatic type arranged for three speed combinations and regeneration in each combination. Two field-control positions are available in each combination giving three running positions in each combination making a total of 12 running positions. The maximum operating speed of the locomotive is 110 k.p.h. (68.3 m.p.h.).

The Operation of Radio Receiving Tube Filaments on Alternating Current

PART II

By DR. K. H. KINGDON and H. M. MOTT-SMITH, JR.
Research Laboratory, General Electric Company

The reduction, to a minimum, of the inherent disturbances present when operating tubes on a-c. as amplifiers were dealt with in Part I. In the present contribution (Part II) tubes used as grid-leak detectors are the subject of discussion. A brief summary gives the gist of the work done.—EDITOR

Secondary Potential Ripple

WHEN a resistance is inserted in the grid circuit, and the grid is allowed to draw current, as in grid-leak detection, the fluctuations in grid current, due to the variations in filament voltage, produce corresponding fluctuations in the grid potential. These in turn give rise to a periodic variation in the plate current which we call the *secondary potential ripple.*

In order to calculate the disturbance in the grid current we need to know something of the grid characteristic. If we take such a characteristic with a small or zero voltage drop in the filament, then it appears that for a great many tubes, embodying widely different types of geometry and shape of grids, the grid current i_{go} can be represented as a simple exponential function of the grid voltage E_g over a certain range. A typical characteristic is illustrated in Fig. 10. The currents considered represent a flow of electrons to the grid. The graph of log i_{go} plotted against E_g is practically linear for sufficiently negative grid voltage. Above a certain potential (E_o) however it begins to depart appreciably from the asymptotic line, becoming concave toward the axis of voltages. The curvature increases rather sharply at a second point E_1, and if i_{go} be plotted against E_g this curve is found to have a point of inflection at E_1. Beyond E_1 the graph of i_{go} continues to be concave downward for a considerable range of grid voltage, but the curvature begins to diminish once more shortly after E_1 is passed. Eventually the curve passes through a second point of inflection, and becomes concave upward as the current begins to obey the three-halves power law. This part of the characteristic however, corresponds to grid voltages which are far greater than those used in detection.

The equation of the part to the left of E_o can be written

$$i_{go} = c\,\epsilon^{\frac{eE_g}{kT}} \tag{36}$$

where e is the charge of the electron, k the gas constant, c the ordinate at E_o and T a temperature which usually is near that of the cathode.(8) The point E_o lies near the cathode potential.

This is precisely what we would expect if the grid were surrounded by an "atmosphere" of electrons having a Maxwellian distribution of velocities, which would imply that there were as many electrons of a given velocity moving in a given direction as in the opposite direction. In such a case each unit of area of the grid surface would receive the same current, and this current would be given by Boltzmann's equation, *i.e.*, of the form of Equation (36), as long as the electric field at the surface of the grid was such as to repel the electrons. In Equation (36) T would then be the temperature of the Maxwellian distribution.(9)

In the case of a thermionic tube, however, conditions cannot be as simple as this. Although the electrons are emitted from the cathode with a Maxwellian distribution of velocities, they have in addition to their Maxwellian velocities a large component of motion in the direction of the anode by the time they reach the neighborhood of the grid. Moreover, the part of the grid which receives the current is effectively restricted to a very narrow region directly facing the filament. Also, the distribution of normal voltage gradient over the surface of the grid is very non-uniform; as the voltage of the grid is raised, the electric force for electrons eventually becomes directed toward the grid surface on the side facing the filament, while it remains directed away from the grid on the side toward the plate. Under these conditions it can scarcely be expected that Boltzmann's equation should hold, so that (36) can only be looked upon as an empirical formula. As a matter of fact, the temperature T determined from it is often found to differ considerably from the cathode temperature.

Taking up now the influence of the voltage drop along the filament on the grid current, let us assume that the grid spacing, emission and resistance per unit length are uniform along the filament. Then the total grid current is found by an integration along the length of the filament, which in this case can be replaced by an integration with respect to voltage. We will consider only the case where the grid return is made to the voltage center of the filament. In Fig. 11 let the curve ACE represent a portion of the grid characteristic for $e_f = 0$, and let the abscissa (E_g) of the point H be the potential of the grid with respect to the voltage center of the filament. If on either side of H we mark the points F and G at a distance $e_f/2$, then the total current to the grid is proportional to the area $FAEG$. On the other hand, for zero filament drop the current is proportional to the area of the rectangle $FDBG$, assuming for the moment that the grid voltage (E_g) does not change as e_f varies (grid leak short-circuited). The difference between the values of the grid current for maximum filament voltage, and for zero filament voltage is, therefore, proportional to the difference between these two areas; or what is the same thing, to the area CBE less the area ADC. The sign of this difference may be said, speaking loosely, to depend upon the average curvature of the grid characteristic between A and C. When this curvature is upward the grid current is greatest when the filament voltage is at its maximum, while if the curvature is downward, the current is greatest when the voltage drop is zero.

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(8)Groeneveld, v. d. Pol. and Posthumus have already remarked this feature of the grid characteristic.
Zs. f. Hochfrequenztechnik 29, 139 (1927).

(9)Cf. Langmuir and Mott-Smith, "Studies of Electric Discharges in Gases at Low Pressures," GENERAL ELECTRIC REVIEW, 27, 449 (1924).

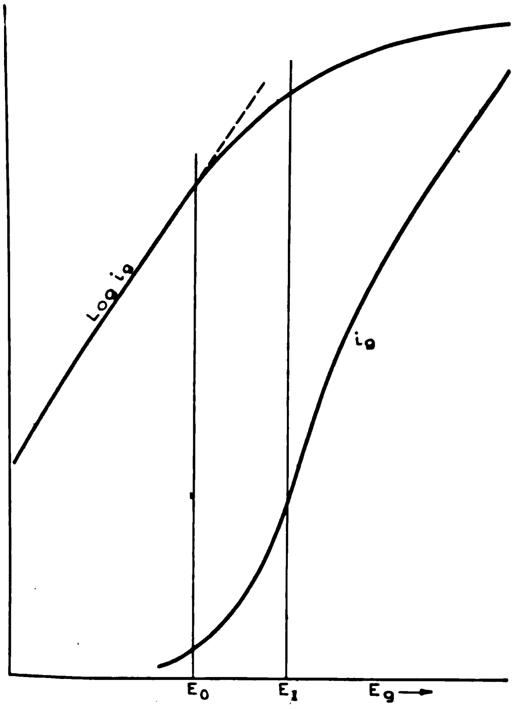

Fig. 10. Typical Grid-current Characteristic

With the grid leak in circuit there will be changes in E_g produced by the variations in e_f. Since in Fig. 11, a positive ordinate represents an electron current flowing toward the grid, an increase in the total grid current (i_g) will make the grid more negative, due to the resistance in the grid circuit. In the case illustrated, where the grid characteristic has upward curvature, the grid current is greatest when e_f is maximum. Supposing that the grid battery voltage is adjusted so that E_g retains its original value for maximum e_f, then the grid voltage will move to a more positive value (E'_g) when e_f becomes zero. The total grid current (for $e_f = 0$) is now proportional to the area $FD'B'G$, so that the fluctuation is proportional to the difference between the areas $C'B'E$ and $AD'C'$. The amount of fluctuation is, therefore, decreased by the presence of the grid resistance, but its sign remains the same as for zero grid resistance.

The variation of the grid voltage between the limits E_g and E'_g produces corresponding changes in the plate current. The ripple so produced has twice the frequency of the filament heating current. In the case illustrated in Fig. 11 it is clear that the plate current is greatest when the filament current is zero. Thus, *when the grid characteristic has an upward curvature, the secondary potential ripple has the same phase as the primary magnetic ripple.*

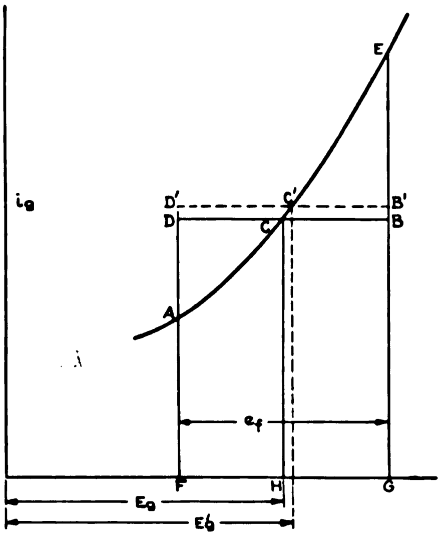

Fig. 11. Influence of Filament Voltage on Grid Current

Let us, however, consider what happens when the grid bias voltage is varied, assuming the grid characteristic to have the shape illustrated in Fig. 10. Starting with large negative voltages, the curvature of the characteristic is upward, and it gradually increases as E_g is made more positive. Thus the secondary plate ripple increases in amplitude until the neighborhood of the point E_o is reached, where the curvature is maximum. Continuing to make E_g more positive the ripple amplitude decreases and finally vanishes when E_g is near the point of inflection E_1. Proceeding beyond this, the amplitude begins to increase once more, but the phase of the ripple is now reversed—it now has the same phase as the primary potential disturbance. The amplitude rapidly reaches a maximum, and then begins to decrease as the curvature of the characteristic once more diminishes. If E_g were made still more positive the ripple would undoubtedly pass through zero amplitude, and then reverse in phase as the second point of inflection is reached and passed. However, no observations were made in this region of the grid characteristic.

For the exponential part of the characteristic the integration indicated in Fig. 11 can be carried out.

Using Equation (36), we find that the total grid current i is given by

$$i_{gm} = c\,\epsilon^{\frac{eE_g}{kT}}\frac{2\,kT}{e\,e_f}\sinh\frac{e\,e_f}{2\,kT} \qquad (37)$$

If we have in the grid circuit a voltage E_b (battery plus contact potential) and a resistance of R ohms, then

$$E_g = -E_b - Ri_{gm}$$

Substituting in Equation (21)

$$i_{gm} = c\,\epsilon^{-\frac{e}{kT}(E_b + Ri_{gm})}\frac{2\,kT}{e\,e_f}\sinh\frac{e\,e_f}{2\,kT}$$

For the instant when $e_f = 0$, $i = i_{go}$ where

$$i_{go} = c\,\epsilon^{-\frac{e}{kT}(E_b + Ri_{go})} \qquad (38)$$

Dividing (37) by (38) we obtain

$$\frac{i_{gm}}{i_{go}}\,\epsilon^{\frac{eR}{kT}(i_{gm} - i_{go}}= \frac{2\,kT}{e\,e_f}\sinh\frac{e\,e_f}{2\,kT} \qquad (39)$$

This equation enables us to determine the fluctuation $i_{gm} - i_{go}$ when i_{go} and e_f are known. We are chiefly interested in the case where this fluctuation is small. By expanding the left-hand side of Equation (39) in powers of $i_{gm} - i_{go}$ and neglecting terms of second and higher orders we find

$$i_{gm} - i_{go} = \frac{1}{\frac{eR}{kT} + \frac{1}{i_{go}}}\left[\frac{2\,kT}{e\,e_f}\sinh\frac{e\,e_f}{2\,kT} - 1\right] \qquad (40)$$

When T is given in degrees Kelvin and e_f in volts this becomes

$$i_{gm} - i_{go} = \frac{1}{11{,}600\frac{R}{T} + \frac{1}{i_{go}}}\left[\frac{T}{5800\,e_f}\sinh\frac{5800\,e_f}{T} - 1\right] \qquad (41)$$

For small values of e_f we can write this with good approximation as

$$i_{gm} - i_{go} = \frac{1}{11{,}600\frac{R}{T} + \frac{1}{i_{go}}}\left[\frac{1}{24}\left(\frac{e\,e_f}{kT}\right)^2\right] \qquad (42)$$

Formula (42) gives the grid current fluctuations as a function of the maximum filament voltage e_{fm} for that part of the grid characteristic which obeys the exponential law (36). It will not give correct results, however, if E_g is more positive than the value E_o of Fig. 10. For such values of E_g, in default of an equation to represent the grid current, graphical or numerical integration must be used.*

This treatment may be illustrated by data taken with a tube specially constructed to give very low ripple when used as a grid-leak detector. The grid and plate were 12 mm. long, the grid consisting of four slats arranged radially. The filament was of 4 mil (0.01 cm.) wire, 6 cm. long, but its ends were covered by shields so that electrons from them could not reach the grid.

The filament runs at about 1000 deg. K. The tube had a μ of 9.8, but, on account of the short electrodes, the mutual conductance was only 260 microamperes at $E_p = 45$, $E_g = 0$. The grid current characteristic has very sharp initial curvature on account of the low filament temperature, so that in spite of the low mutual conductance, the tube is as sensitive a grid-leak detector as the 201-A Radiotron ($G_m = 630$, $\mu = 8.2$). This property of a low-temperature filament has also been noticed by Groeneveld, v.d. Pol, and Posthumus.*

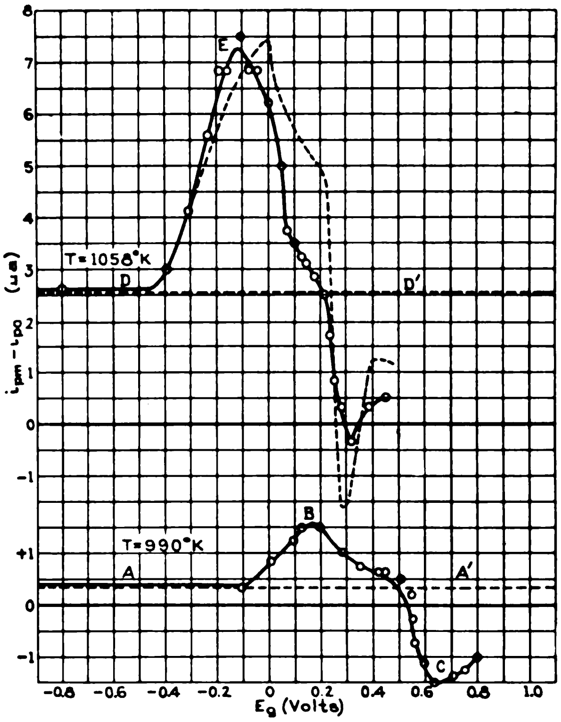

Fig. 12. Secondary Potential Ripple in a Grid-leak Detector Having a Caesiated Filament. Curves are shown for two filament temperatures

Data were taken at $E_p = 45$ volts, with and without a grid leak of 2.4 megohms. The filament potentiometer was adjusted to eliminate the 60-cycle ripple. In Fig. 12 the abscissas are the applied grid potentials with respect to the center tap of the potentiometer, corrected for the potential drop in the grid leak. The ordinates show the double amplitude of the ripple in microamperes. For the lower curve the filament temperature was 990 deg. K, and the potential drop over the center 14 mm. of the filament was 0.104 volt r.m.s. The dotted line AA' shows the ripple when the grid leak was short-circuited. This ripple was of the primary magnetic type. When the grid leak was in circuit, the ripple rose to a maximum at B as the grid was made positive; this extra ripple was due to a potential disturbance in i_g and was of the same phase as the primary magnetic ripple.

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*In several cases it appeared that for the part of the characteristic beyond E_1, the square of i_g was quite accurately a linear function of E_g over a certain range This is the sort of characteristic that would be given by a cylindrical collector immersed in a Maxwellian distribution with accelerating potentials on the collector (Langmuir, Mott-Smith, loc. cit.) and there were even indications that in the transition region between E_o and E_1 the characteristic was also that appropriate to cylindrical collectors. This is rather remarkable, since in most of the cases the grids were of the radial slat form.

*loc. cit.

As the grid was made more positive, the ripple decreased to zero, changed to the opposite phase, and rose to a second maximum at C. This is plotted on the opposite side of the zero line to indicate the difference in phase.

The normal point of operation of the tube as a grid-leak detector would be at about $E_g = +0.3$. There $(i_{gm} - i_{go})$ is about 1 microamp., so that the r.m.s. ripple current would be about 0.35 microamp. The tube impedance was about 40,000 ohms, so that this ripple would correspond to an r.m.s. voltage of 0.007 across a 40,000 ohm impedance (at 120 cycles) in the plate circuit. This ripple could be reduced considerably by using a lower resistance grid leak.

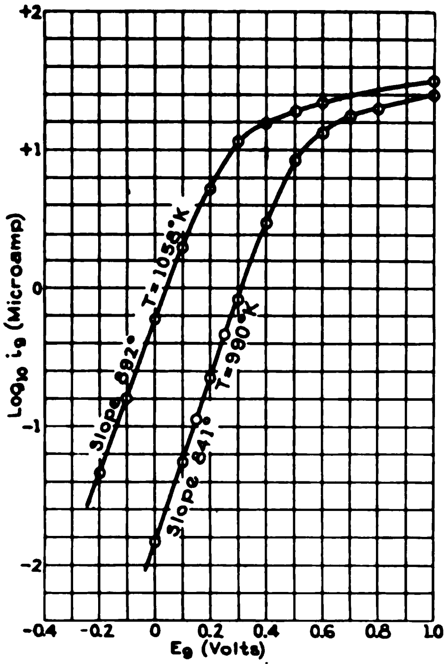

Fig. 13. Logarithmic Plots of Grid-current Characteristics of a Detector with a Caesium-coated (Caesiated) Filament

The upper curve of Fig. 12 gives data taken with a filament temperature of 1058 deg. K, making the drop over the center section of the filament 0.131 volt r.m.s. The dotted line DD' represents the primary magnetic ripple with the grid leak short-circuited. It may be noted here that the primary magnetic ripples DD' and AA' were both considerably less than the calculated values. This was probably due to a partial compensation of the primary magnetic ripple by a primary potential ripple, caused by the shields connected to the ends of the filament.

When the grid leak was in circuit, the potential ripple in i_g caused an additional ripple in i_p which rose to a maximum at E. As before, the ripple decreased at higher grid voltages, but in this case was only observed to change to the opposite phase at one point.

The grid characteristics are shown by a semi-logarithmic plot in Fig. 13, and by a linear plot in Fig. 14. These characteristics were taken with the grid leak short-circuited. E_g measures the voltage applied between the grid and the center tap of a potentiometer connected across the filament. The filament was heated by a.c. for these measurements, and therefore the values of i_g are intermediate between i_{gm} and i_{go}, the values respectively appropriate to maximum and zero heating currents. However $(i_{gm} - i_{go})$ is small, and in our calculations of ripple from Equation (42) we may use i_g instead of i_{go} to an accuracy of about 5 per cent. The grid characteristic for $T = 1058$ deg. K. (Fig. 13) follows the exponential law up to $E_g = 0.1$ and from Fig. 11 we see that we may use Formula (42) up to $E_g = 0$ without the voltage drop over the filament ($e_{fm} = 0.185$ volt) bringing any portion of the filament off the exponential part of the grid characteristic. It should be noted that the slope of the exponential characteristic gives a lower temperature ($T_s = 892$ deg.) than that found from the heating current ($T_c = 1058$ deg. K.) In Formula (42), T_c should be used to determine e_{fm}, but T_s substituted in the formula itself. The data to be substituted into Equation (42) are $T_s = 892$ deg., $R = 2.4 \times 10^6$ ohms, $e_{fm} = 0.185$, and the values of i_g. From the values of $(i_{gm} - i_{go})$ obtained in this way we may get the corresponding values of $(i_{pm} - i_{po})$ by multiplying them by R, and by the mutual conductance $G_M = 2.6 \times 10^{-4}$ amp. The ripple curve calculated in this way up to $E_g = 0$ is the first part of the dotted curve on the plot for $T = 1058$ deg. (Fig. 12). The agreement is as good as could be expected

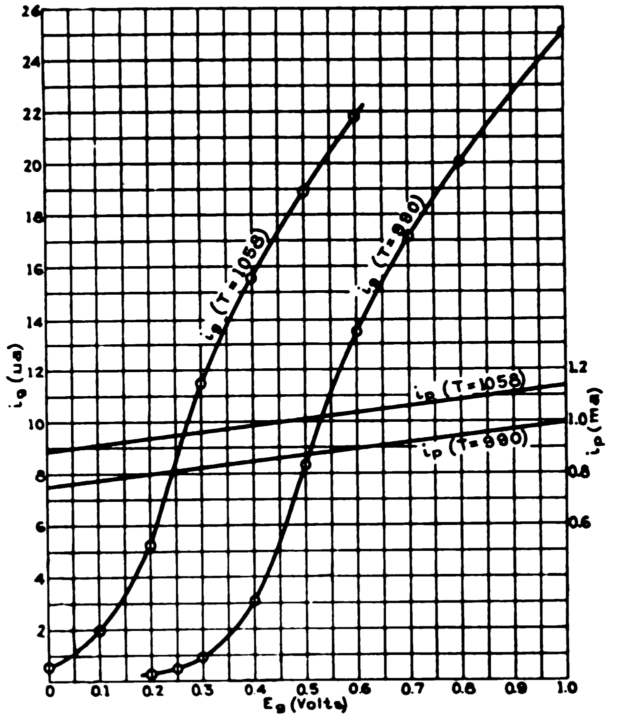

Fig. 14. Linear Plots of Grid and Plate Currents, for the Same Caesiated-filament Tube as in Fig. 12

from the accuracy of the experimental data. To calculate the ripple for the higher values of E_g we must follow some method which takes account of the departure of the i_g characteristic from the exponential law.

From Fig. 14 we see that there is a point of inflection on the grid characteristic at $E_g = +0.25$. As E_g is raised towards this point the secondary potential ripple decreases, due to the decrease in curvature, finally becoming zero for some value of E_g near the point of inflection. Above the point of inflection the ripple changes phase, for i_g will be a maximum when e_f is zero. The plate current will therefore be a minimum when e_f is zero.

The Euler-MacLaurin integration formula gives a convenient method for evaluating the ripple graphically in this region. Select a grid voltage E_o, and two others $E_1 = E_o - e_{fm}/2$ and $E_2 = E_o + e_{fm}/2$. Let the grid currents at the voltages be i_o, i_1 and i_2 respectively. From the Euler-MacLaurin formula we have

$$\int_{E_1}^{E_2} i\,dE - e_{fm}\, i_o = \frac{1}{2}\, e_{fm} \left(\frac{1}{2}\, i_1 - i_o + \frac{1}{2}\, i_2\right) - \frac{1}{48}\, e^2_{fm} \left[\left(\frac{di}{dE}\right)_2 - \left(\frac{di}{dE}\right)_1\right] + \cdots$$

where the subscripts of the differential coefficients denote the values at E_2 and E_1. Dividing through by e_{fm}, we see that if the grid voltage is set at E_o, the first term on the left denotes the grid current when e_f is a maximum, while the second is the current when e_f is zero. We have therefore

$$(i_{gm} - i_{go})' = \frac{1}{2}\left(\frac{1}{2}\, i_1 - i_o + \frac{1}{2}\, i_2\right) - \frac{1}{48}\, e^2_{fm} \left[\left(\frac{di}{dE}\right)_2 - \left(\frac{di}{dE}\right)_1\right] + \cdots \quad (43)$$

The values of di/dE were obtained graphically. As calculated from Equation (43), $(i_{gm} - i_{go})'$ is the change in grid current which would take place if there were no external resistance in series with the grid. If there is a grid leak of resistance R in series with the grid, and if the grid impedance is $(dE/di)_o = r$, the fluctuation in grid current will be approximately

$$(i_{gm} - i_{go}) = (i_{gm} - i_{go})' \frac{r}{r + R}$$

As before, the fluctuation in plate current will be

$$(i_{pm} - i_{po}) = (i_{gm} - i_{go})\, R\, G_m \quad (44)$$

The values of $(i_{pm} - i_{po})$ calculated from (44) agree with those calculated from the exponential formula (42) at $E_g = 0$. Values at higher E_g are shown by the dotted curve on the 1058-deg. plot of Fig. 12. The reversed phase part of the ripple is sufficient to slightly overbalance the primary magnetic ripple at some points. This is still more noticeable in the 990-deg. plot of Fig. 12.

It thus appears that all the extra ripple caused by a grid leak may be attributed to a secondary potential ripple. No effects indicating an appreciable temperature or magnetic ripple in i_g have been found.

SUMMARY

Part I: The use of alternating current for heating the filament of a vacuum tube gives rise to three effects: (1) a fluctuating potential drop along the filament, (2) a fluctuating magnetic field around the filament, and (3) fluctuations in filament temperature. When the tube is used as an amplifier (no grid current) these fluctuations cause three kinds of disturbances in the anode current which we shall call respectively: (1) the primary potential ripple, (2) the primary magnetic ripple, and (3) the primary temperature ripple.

The voltage ripple (Section II) may be reduced to a minimum residual by connecting the grid and anode returns to the center of a potentiometer across the filament; and in what follows we shall assume that this has been done. The residual voltage ripple is of double the frequency of the heating current, and of such a phase as to make the anode current a maximum when the filament current is a maximum. Its magnitude is given by Equation (5). Section II contains also a treatment of the effect on the voltage ripple of irregularities in the distribution of anode current along the filament, and of the presence of harmonics in the heating current.

The magnetic ripple (Section II) has a frequency double that of the heating current, and its phase is such as to make the anode current a minimum when the filament current is a maximum. Its magnitude is given by Equation (32). Since these two ripples are of opposite phase they may be made to neutralize one another. This is done by a suitable choice of tube voltages and filament resistance, as indicated by Equation (33).

The temperature ripple (Section V) is of importance only when the anode current takes a large fraction of the total emission of the filament. It is also of double frequency, and lags 90 degrees in phase behind the voltage ripple.

In Section VI, the formulas given in the preceding sections are compared with experiment, and found to be quantitatively correct.

Part II: When the grid is made positive enough to take electron current, disturbances occur in the grid current which are similar to those in the anode current, which were described in Part I. If the grid current flows through a grid-leak resistance, the fluctuations in grid current cause fluctuations in grid potential, which in turn give rise to "secondary" ripples in the anode current. Usually the secondary potential ripple is of by far the greatest importance. This is a double-frequency ripple, ordinarily of opposite phase to the primary potential ripple. It is discussed quantitatively in Section VII. This ripple is so large as to give rise to serious disturbances in a tube used as a grid-leak detector, if the filament drop is greater than about 0.1 volt.

(*Concluded*)

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Alternators

Large Hydro-Electric Generator Repaired by Unique Method. E. J. Kingsbury.
Power, Jan. 22, 1929; v. 69, pp. 126-128.
(Illustrated account of methods used in repairing a waterwheel alternator that was damaged in the flood due to the breaking of the St. Francis dam.)

Arc Welding

Inspection of Structural Steel Welding. Cyril D. Jensen.
Am. Weld. Soc. Jour., Jan., 1929; v. 8, pp. 6-14.

Carrier-current Communication

Transmission of High-frequency Currents for Communication Over Existing Power Networks. C. A. Boddie and R. C. Curtis.
A.I.E.E. Jour., Jan., 1929; v. 48, pp. 37-41.
(Abridgment.)

Corona

Corona Eliminated in High-Voltage Generators. Charles F. Hill.
Elec. Wld., Jan. 19, 1929; v. 93, pp. 139-140.

Electric Cables

New Development in Oil-Filled Cable Design. G. B. Shanklin and V. A. Sheals.
Elec. Wld., Jan. 12, 1929; v. 93, pp. 97-102.
("Sectionalized balanced pressure design of three-conductor liquid oil-filled cable. Description of 33-kv. installation in Chicago and data on construction and tests.")

Electric Control Systems

Control of Multiple Street Lighting. George I. MacKenzie.
Elec. Wld., Dec. 29, 1928; v. 92, pp. 1292-1294.

Insulation

Insulation; The Opportunity for Research. J. B. Whitehead.
A.I.E.E. Jour., Jan., 1929; v. 48, pp. 27-31.
(An address to the Committee on Electrical Insulation. National Research Council.)

Machinery—Assembly Methods

Large Rotor Heated Electrically for Shaft Assembly.
Elec. Wld., Jan. 19, 1929; v. 93, pp. 138-139.
(How the Southern California Eidson Co. heated a rotor by means of eddy currents and hysteresis loss.)

Protective Apparatus

Arcing Ground Suppression as Basis for Safe Operation of Super Power Systems. R. Troeger.
AEG Progress, Dec., 1928, v. 4, pp. 371-378.

Radio Engineering—Measurements and Testing

Measurements on Broadcast Receivers. L. M. Hull.
Radio Broadcast, Feb., 1929; v. 14, pp. 230-232.

Railroads—Electrification

Great Northern Electrification Extended.
Elec. Rwy. Jour., Jan. 19, 1929; v. 73, pp. 110-113.
(Includes consideration of the new Cascade Tunnel.)

Turbine-Generators

Double-Winding Generator Solves Breaker Problem. D. D. Chase and H. C. Forbes.
Elec. Wld., Dec. 15, 1928; v. 92, pp. 1183-1186.
(Discusses the three plans considered for handling the output of a 160,000-kw., single-shaft unit for East River station of the New York Edison Co.)

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.*)*

Geschichtliche Einzeldarstellungen aus der Elektrotechnik. 98 pp., 1928, Berlin, Julius Springer.
(This is apparently the first of a series of little historical sketches, in German, on the development of electrical engineering, and is sponsored by the Elektrotechnischen Verein E. V. It deals with the history of the transformer and of the electric meter. Of the five essays included, four are on the transformer, two being contributed by Gisbert Kapp and one each by L. Schuler and Dolivo-Dobrowolsky. W. Stumpner provides the single essay on the history of the electric meter. Numerous bibliographic footnotes refer to the literature consulted.)

Die Gleichstrom-Querfeldmaschine. E. Rosenberg. 97 pp., 1928, Berlin, Julius Springer.
(This little German booklet is devoted to an account of the theory and applications of the so-called Rosenberg direct-current generator developed by the author in 1904 for car-lighting purposes. The first twenty pages explain the theory of the machine. Then follows information on its uses in car lighting, arc welding, and for other applications. The author also reviews the mathematical investigations of his machine by Kuhlman and Hahnemann and by Thomälen. A short list of references to literature on the subject brings the little volume to a close.)

Introduction to Theoretical Physics. Leigh Page. 587 pp., 1928, N. Y., D. Van Nostrand Co., Inc.
(The author, who is Professor of Mathematical Physics at Yale University, says of this volume that it "is designed as a text for first-year graduate students and for college seniors who are specializing in physics. Its aim is to provide the student in an elementary way with a survey of the whole field of theoretical physics. The only mathematics required of the reader in advance is a good working knowledge of the differential and integral calculus, and an acquaintance with the elements of differential equations. . . The treatment is sufficiently detailed so that the reader is able to follow the development step by step, and illustration problems are interspersed throughout to make the principles clearer. The subject matter is divided into five main headings: Dynamics, Hydrodynamics, Thermodynamics and the Kinetic Theory of Gases, Electro-magnetism, and Optics and Spectroscopy.")

Vibration Problems in Engineering. S. Timoshenko. 351 pp., 1928, N. Y., D. Van Nostrand Co., Inc.
("The fundamentals of the theory of vibration are developed, and their application to the solution of technical prolems is illustrated by various examples, taken, in many cases, from actual experience with vibration of machines and structures in service." The text is divided into five main headings: Harmonic Vibrations of Systems Having One Degree of Freedom, Non-Harmonic Vibrations of Systems Having One Degree of Freedom, Systems Having Several Degrees of Freedom, Vibration of Elastic Bodies, and Vibration Measuring Instruments. The theory underlying such practical problems as the following is presented: balancing of machines; critical speeds and vibrations in machines; vibration in bridges; torsional vibrations in shafts; whirling speeds of shafts having several supports; dynamic vibration absorbers; vibrations in membranes, discs, turbine blades, and the hulls of ships; and other engineering problems where vibratory forces must be considered.)

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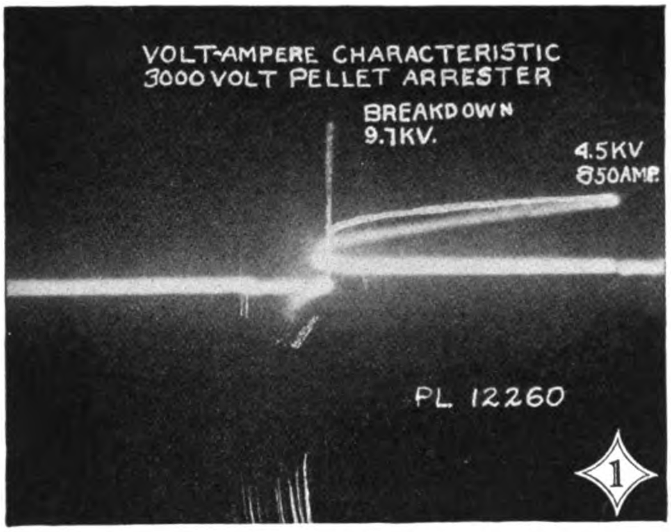

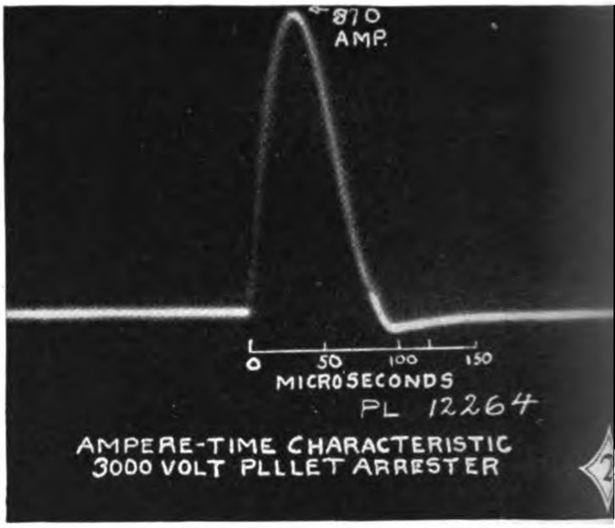

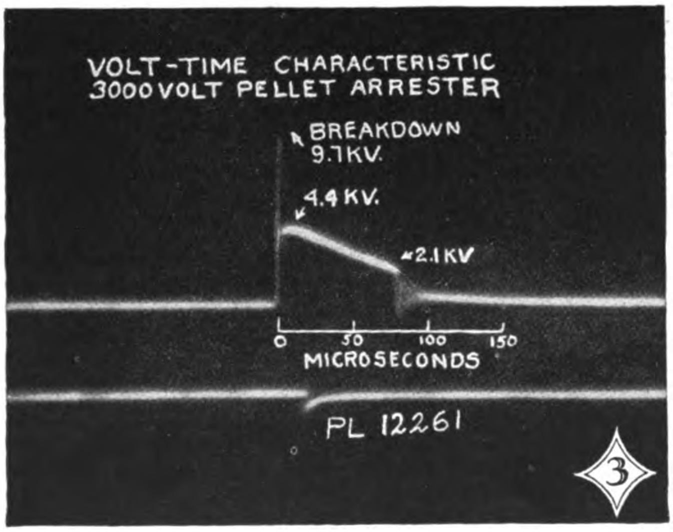

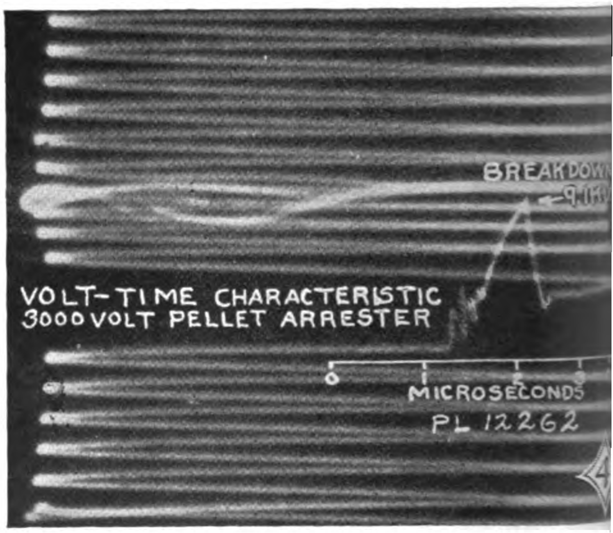

GENERAL

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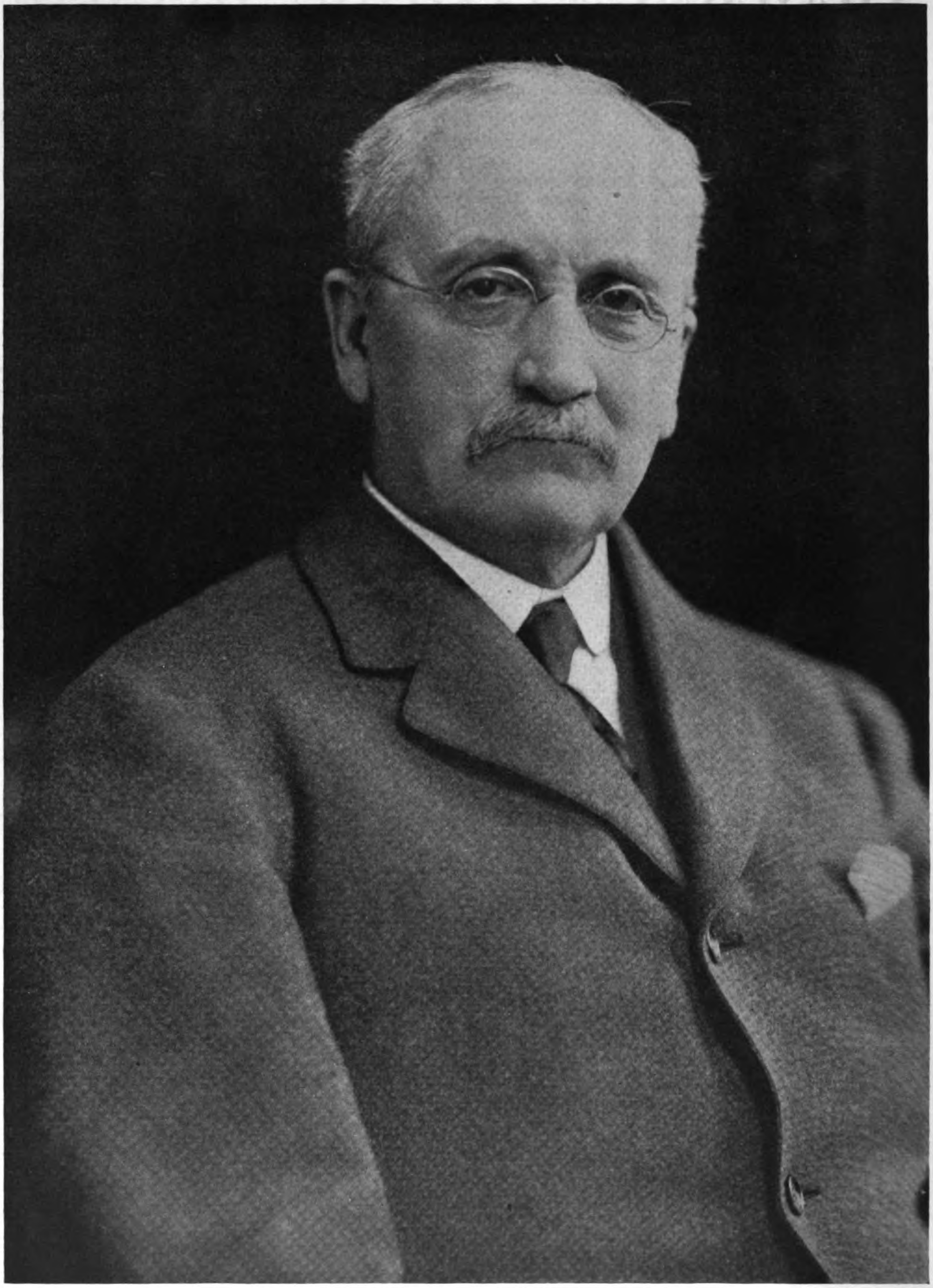

WILLIAM LeROY EMMET
Consulting Engineer of the General Electric Company
and
The Father of the Electric Ship

GENERAL ELECTRIC
REVIEW

Vol. 32 May, 1929 No. 5

ELECTRIC SHIPS

We are told that the first steamboat began to ply on the Clyde in the year 1812; and that it was of three horsepower and moved at five miles an hour.

On August 18, 1928, the *Virginia*, sister ship of the *California*, was launched. Both are Electric Ships. The *Virginia's* two 8500-hp. electric motors can drive her 30,000 tons through the seas at 18 knots. And this is as nothing to what Electric Ships can do, and have done.

The U. S. Airplane Carriers, the *Saratoga* and *Lexington*, can develop over 200,000 hp. and make speeds considerably in excess of 30 knots.

Could anything be more symbolic of modern progress than Electric Ships? But with all this progress is there any one who really loves the sea that does not feel like shedding a tear to the memory of the picturesque old sailing ships of our grandfather's days—

> "Long since, when all the docks were filled
> With that sea beauty man has ceased to build."

But if we look aright there is always something more wonderful in the new than in the old. How many thought that steam must spoil romance at sea? But not so to McAndrew, "the dour Scots engineer" or to any one who has served his apprenticeship at building marine reciprocating engines; and who, after running many trials at sea, has stood watch with his old "beasties" in an old-fashioned engine room with an old-fashioned boiler room hard by. Steam gave a new, if different, romance at sea; and to any one who loves the old marine engine, Kipling's "M'Andrew's Hymn" (written in 1893) is more beautiful than many Psalms.

We have met so many men at sea like McAndrew, "the auld Fleet Engineer"—

> "That started as a boiler-whelp—when steam and he were low.
> I mind the time we used to serve a broken pipe wi' tow!
> Ten pound was all the pressure then—Eh! Eh!—a man wad drive:
> An' here, our workin' gauges give one hunder sixty-five!
> We're creepin' on wi' each new rig—less weight an' larger power;
> There'll be the loco-boiler next an' thirty miles an hour!
> Thirty an' more. What I ha' seen since ocean steam began
> Leaves me na doot for the machine; but what about the man?
> The man that counts, wi' all his runs, one million mile o' sea."

But it is inevitable that mechanical, and electrical, evolution must follow in the footsteps of organic evolution, and bury many an old friend soon after a more efficient wonder is created and developed. And so the death knell of the old reciprocating engine was sounded when the first turbine was put in a ship. We knew then that the "Sublime Orchestra" of the old engine room, that we loved so dearly, and that McAndrew wanted a "Bobbie" Burns to sing of, was doomed to give way to the gentler hum of the turbine; and later to the more modern duet of the turbine humming and the electric motor "purring" together in harmony.

> "Lord, send a man like Robbie Burns to sing the Song of Steam!
> To match wi' Scotia's noblest speech yon orchestra sublime
> Whaurto—uplifted like the Just—the tail-rods mark the time.
> The crank-throws give the double-bass, the feed-pump sobs an' heaves,
> An' now the main eccentrics start their quarrel on the sheaves:
> Her time, her own appointed time, the rocking link-head bides,
> Till—hear that note?—the rod's return whings glimmerin' through the guides.
> They're all awa'! True beat, full power, the clangin' chorus goes
> Clear to the tunnel where they sit, my purrin' dynamos.
> Independence absolute, foreseen, ordained, decreed,
> To work, Ye'll note, at any tilt an' every rate o' speed.
> Fra' skylight-lift to furnace-bars, backed, bolted, braced an' stayed,
> An' singin' like the Mornin' Stars for joy that they are made;
> While, out o' touch o' vanity, the sweatin' thrust-block says:
> "Not unto us the praise, or man—not unto us the praise!"
> Now, a' together, hear them lift their lesson—theirs an' mine:
> "Law, Order, Duty an' Restraint, Obedience, Discipline!"
> Mill, forge an' try-pit taught them that when roarin' they arose,
> An' whiles I wonder if a soul was gied them wi' the blows.
> Oh for a man to weld it then, in one trip-hammer strain,
> Till even first-class passengers could tell the meanin' plain! '

While some may have keen regrets for a faithful old friend who is doomed to be displaced by a more efficient rival, we must all admit the rival's superiority. It was only a few years after the advent of the steam turbine in marine service that we could

> "Take the Western Ocean in the stride
> Of thirty thousand horses and some screws."

Only a few years ago many "knew" that an electric motor could not "make good" at sea. What!—add an electric generator and an electric motor to the still essential boiler and steam turbine? Absurd! But today we know that the electric ship has come to stay, and that those built and building now are but the forerunners of the much more marvelous electric ships of the future.

Those inherent advantages of the electric method of generating, transmitting, converting, controlling, and applying power which have led to the electric motor, either partially or wholly, displacing all other methods in our factories, on our railways, and in our homes and offices, etc., will some day lead to its universal adoption on all our larger ships. It is inevitable.

We are fond of singing the praises of those whose work and courage in the past have led to revolutionary changes in our method of doing things, but are likely to neglect the work of our friends of contemporary date. So let us here pause to raise our hat in acknowledgment of the courage, skill, patience and engineering ability of W. L. R. Emmet, that great Engineer of our time, whose persistence—against much opposition—gave us the Electric Ship.

> "An' by that light—now, mark my word—we'll build
> the Perfect Ship."

What the "Perfect Ship" of the future will be like—who can say? One thing seems certain, it will be an electric ship. How many years will it be before all passengers will insist on the comfort, speed, and luxury that an electric ship affords? In twenty-five years from now how many passenger ships crossing the Atlantic and Pacific will be anything but electric ships?

It would be interesting, if useless, to speculate on what the future ship will be like. Consider the modern development of the art with automatic substations and automatic power houses, the possibilities of yet further improvements in automatic oil-fired boilers, the possibilities of Emmet's mercury-vapor boiler, and its first cousins, yet to come, and our modern methods of the remote control of power. With these in mind we cannot help visualizing the passing of the old engine room and old boiler room at sea. The future ship's boiler and engine room staff will look a lot more like a bunch of bishops on church parade than the grimy stokers and engineers of twenty years ago!

Will everything be remote control from the bridge? Will the ship of the future be steered absolutely automatically by a gyroscopic compass? Will the electric ship of the future leave one port and arrive at its destination under the control of a single hand?

> When "her captain turns the lever 'neath his hand,
> And the monstrous nine-decked city goes to sea."

J. R. H.

"Long since, when all the docks were filled
With that sea beauty man has ceased to build."

Edison's First Commercial Lamp

By **CHARLES L. CLARKE**
Research Laboratory, General Electric Company

> *By nature, Edison is a maker of history not a historian. Blessed with an inexhaustible store of energy, he forges ahead always intent upon the task of pushing aside the obstacles that lie between him and his next goal. In obtaining the following record of one of his early goals, we are fortunate in having secured Charles L. Clarke as author for he was intimately connected with Edison's work at that time.*—EDITOR

EDISON knew on October 21, 1879, after months of intensive effort, that in all its fundamentally essential details he had at last invented an electric lamp to take the place of the ordinary gaslighting burner, and thus had solved the problem popularly known as "subdivision of the electric light" which for years had been talked and written about, often attempted, and even been declared impossible by more than one eminent scientist. He realized he had attained his achievement after discovering the surprising endurance of a carbonized cotton-thread electric burner, when brought up to brilliant incandescence in an all-glass globe exhausted to nearly a perfect vacuum, and made permanently air-tight by having the conducting wires sealed into the glass by fusion.

This first successful incandescent electric lamp was broken open, and thus destroyed, in order that reasons for the remarkable performance of such an attenuated and delicate burner might be found out, as far as the microscope would reveal them. Thus the atmosphere of romance, which has surrounded this lamp by reason of the dramatic suddeness with which it flashed out of a previous darkness in the art of electric lighting, has not attached to its physical self, but is preserved only in the memories of its inventor and Francis Jehl, at that time a laboratory assistant, the last of those now living who heard the "Eureka" which greeted it, and in historical accounts of the lamp and attending circumstances, which preëminently include United States Patent 223,898 for which application was made on the following November 4th, just two weeks after the great discovery, and wherein the outstanding characteristics of a carbonized cotton-thread burner were set forth, and the term "filament" was applied by Edison to his burner, which name still survives for the burners of all incandescent lamps.

In so far as the public was concerned, however, the romance of the Edison lamp was to come just a little later and apply to the so-called horseshoe lamp; the people knew nothing yet of the existence of a successful Edison lamp. In the same November, the inventor, with his inborn railway speed of working, went from cotton thread and various other materials to filaments of carbonized visiting-card bristol board, cut in oval loop-form with enlarged ends for more efficiently connecting the filament with the conducting wires by means of tiny screw-clamps of platinum. The form of these burners gave them the name of "horseshoe" filaments; and the lamps became horseshoe lamps, destined to the honor of being the first commercially used lamps.

Lamps of this character were made as rapidly as limited laboratory facilities permitted; supply wires were strung through the machine shop and laboratory, and overhead on poles to the homes of Edison and some others, and to a few wooden lamp-posts along nearby grass-grown streets in the hamlet of Menlo Park (N. J.), where his laboratory enterprise for research and invention had been established three and a half years before. As fast as lamps were made they were installed at these various places for observation and life-test as well as for practical use.

Soon the rumor began to spread that Edison had made a great invention—an electric light that would supersede gaslighting.

Excitement about it began to grow. At night passengers on Pennsylvania Railroad trains pressed their faces against the windows to see the lamps at the top of the high embankment stairs at Menlo Park station, and a few stray visitors began to filter in, mainly from the region round about; but the visiting continued in increasing volume and from more distant parts, until, on Sunday, December 21st, the *New York Herald* published its famous illustrated article on "Edison's Light," in which the horseshoe lamp was first authentically announced, but incorrectly illustrated, however, with an earlier experimental and discarded means of connecting the filament with the conducting wires. Whereupon Menlo Park became overnight a Mecca for the curious and interested, who came from the cities by thousands during the Christmas season, mainly to see, wonder, and exclaim; for very little, if anything at that day, did they know about the true inwardness of what they saw.

The news about the lamp went round the world; gas stocks tumbled, while stock of the little Edison Electric Light Company mounted to almost fabulous figures. But in all the excitement outside, the Menlo Park establishment remained calm. It still had wearing work to do that the public knew nothing about; for although the little lamps continued to burn on serenely in gradually increasing numbers there was at first a strange fickleness in their life. With no practically observable difference between them, some lamps failed almost immediately or in a comparatively short time, although most of them encouragingly kept on for perhaps a hundred or several hundred hours, and in a few instances for upward of a thousand hours.

Edison went to work to even things up, to raise the average life with a fairly minimum departure from it, and practically to eliminate quick failures. This was soon satisfactorily accomplished for that time in the art, particularly by improving and systematizing means and method for carbonizing the filaments and exhausting the lamps. The normal life finally attained was around 300 hours. (1) From their thread-like tenuity, combined with the limited elasticity of carbonized bristol board, however, the filaments continued sensitive to mechanical shock by which they were apt too easily to be broken. Concurrently with this work, Edison was naturally searching for a more durable filament material, both electrically and mechanically, which at the same time would permit operation at still higher incandescence and thus at greater candle-power efficiency.

TABLE I

PERFORMANCE CHARACTERISTICS

Volts	Amperes	Watts	Ohms	Candle Power Max. Horiz.
0.0	0.0	0.0	123	0
12.654	0.111	1.405	114	0
14.448	0.129	1.864	112	Just visible
18.204	0.164	2.985	111	Dull-red
25.334	0.239	6.055	106	Cherry-red
33.934	0.361	12.250	94	0.016
40.050	0.445	17.822	90	0.10
48.783	0.578	28.197	84.4	0.50
52.584	0.626	32.968	84	0.83
53.728	0.645	34.655	83.3	1.10
55.440	0.672	37.256	82.5	1.5
64.880	0.811	52.618	80	4.5
70.461	0.908	63.978	77.6	9.2
80.386	1.079	86.736	74.5	20.0

The horseshoe lamps were, however, performing such good service at Menlo Park that at the urgent desire of Henry Villard, then a director in the Edison Electric Light Company, and president of the Oregon Railway and Navigation Company, a contract was entered into by the two companies under which the new steamship *Columbia* of the latter company was equipped at New York City with a complete Edison lighting plant which included 115 horseshoe lamps, rated at 16 candle power and known as "A" lamps. The installation was started in operation on May 2, 1880, and a few days later the *Columbia* began her voyage around the Horn to the Pacific Coast and arrived at Portland, Oregon, on July 26th, with a cargo of locomotives, cars, and other railway equipment.

The *Columbia's* lighting plant was a perfect success during the long voyage. But in the meanwhile, Edison had found out the far superior virtues of carbonized bamboo over bristol board, and had shipped bamboo-filament lamps overland to meet the ship upon her arrival. Thus ended the commercial career of the horseshoe lamp—romantic under all the circumstances, even though brief. It at least filled the commercial bill until a better filament came along. Incidentally, the bamboo lamp continued to be the Edison lamp in common use until 1894.

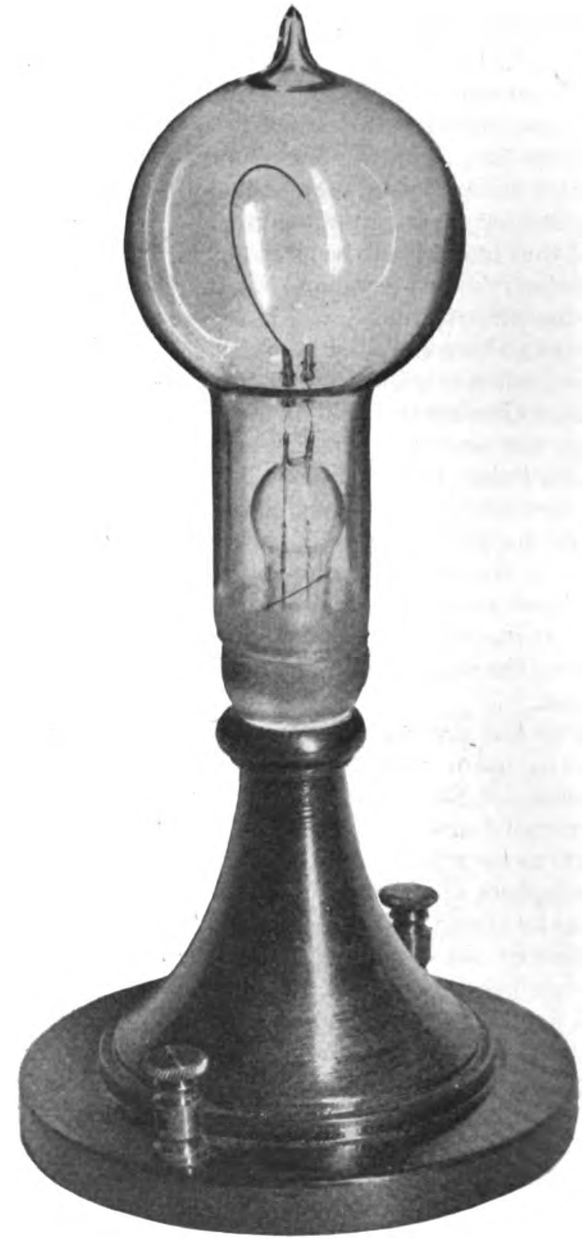

Fig. 1. Photograph of One of the Original Edison Lamps Used in Commercial Service. Lamps of this carbonized bristol-board, "horseshoe" filament type were produced from November, 1879, to May, 1880. In this illustration the lamp is shown approximately ¾ size. Actual dimensions (in inches): total height $8\frac{1}{16}$; diameter of base $3\frac{11}{16}$; bulb diameter $2\frac{5}{16}$; length of bulb neck from bulb to stem seal $1\frac{7}{8}$

---

(1) "Edisonia: a Brief History of the Early Edison Electric Lighting System," New York, 1904. Published by the Association of Edison Illuminating Companies. See p. 103 in an illustrated article on lamps, by William J. Hammer, who was employed in Edison's laboratory.

In the hurly-burly of pushing rapid lamp improvement, coupled with the stress of developing the thousand-and-one other details of his electric central-station system, this energetic doer, Edison, permitted little time and cared less for the systematic recording and sure preservation of what had been done, but was ever disposed to forget the technically old and hasten on to the better new. Consequently, today we should doubtless be at a loss for precise performance data relating to the horseshoe lamp, were it not for tests, by Professor Henry Morton and others at the Stevens Institute of Technology, upon a lamp obtained from Edison through the *Scientific American*. Meager results of the tests were published in that journal, April 17, 1880, but fortunately a complete account was rendered by Professor Morton in an official government report(2) dated at Hoboken (N. J.), November 29, 1880, four months after the horseshoe lamp had been superseded by the bamboo lamp. The report contained a small woodcut of the lamp mounted on a Menlo Park made wooden stand with binding posts (with improper omission of the lamp-bulb tip, however), also a description of test apparatus used and methods of measurement followed, tabulated test results, and curves illustrating the relation of resistance to horizontal-face candle power and to horsepower consumed, relation of candle power to horsepower and relation of angle between plane of filament loop and axis of photometer to candle power. Table I is derived from tabulated data in the Morton report.

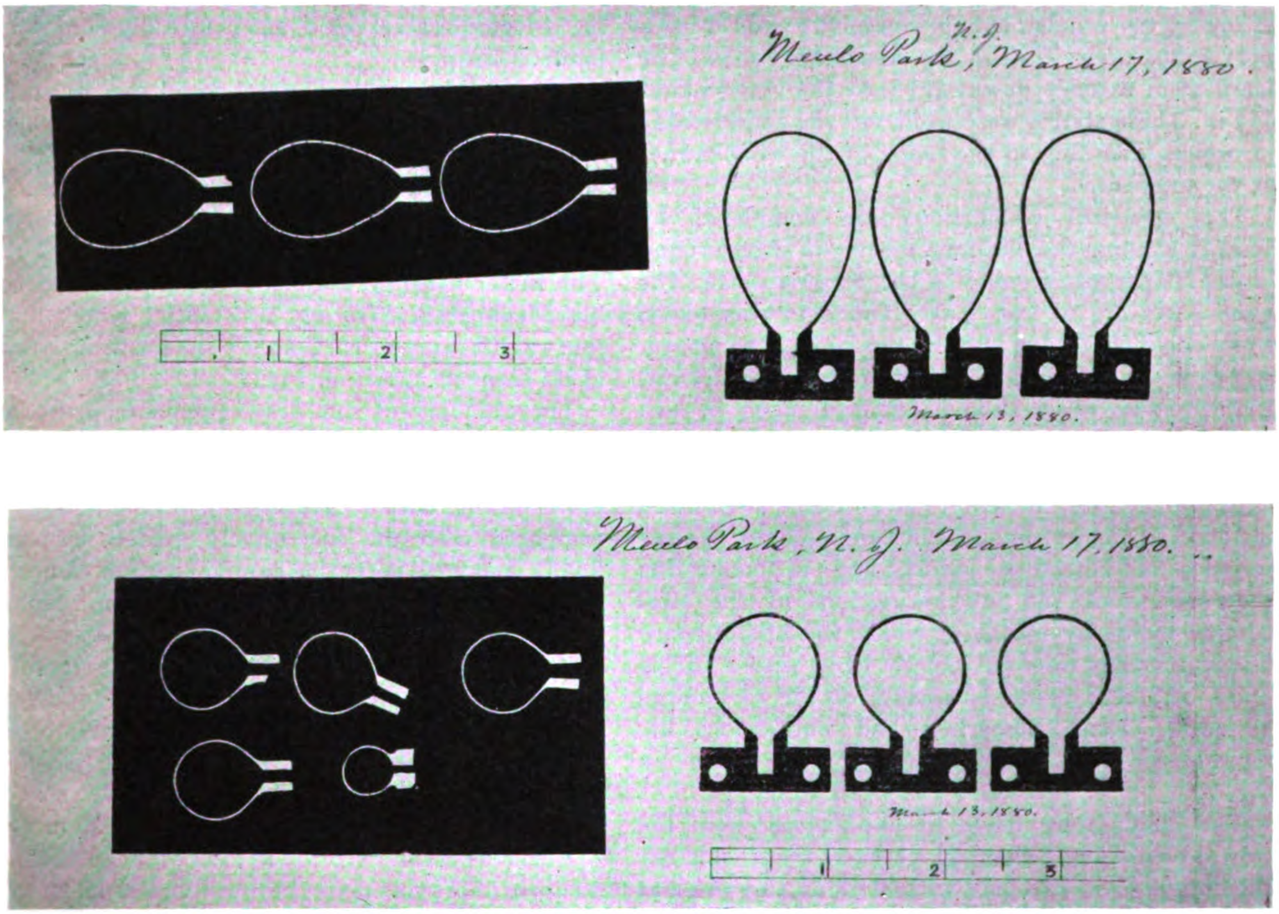
Menlo Park, N.J. March 17, 1880.
March 13, 1880.
1
2
3
Menlo Park, N.J. March 17, 1880.
March 13, 1880.
1
2
3

Fig. 2. Records of the Shape and Size of the Bristol-board "Horseshoe" Filaments for Edison's First Commercial Lamp. At the right are impressions of the steel dies used in blanking out the filaments and at the left are contact blue-print impressions of the filaments after carbonizing. The width of the large filaments before carbonizing was 25 mils and the small filaments 30 mils; and the thickness 6.5 mils. Carbonizing produced a linear shrinkage in the ratio of 15 to 11

The arithmetical mean of ten candle-power readings, ten degrees apart from face (20.6 candles) to edge (6.7 candles), was 69.2 per cent of the face value.

The accompanying figures may be taken as representing about the average performance characteristics of good horseshoe lamps, bearing in mind that there was more or less variation between individual lamps, especially in respect to voltage required to obtain the nominal 16 candle power. This variation also persisted with the bamboo lamps for the first few years of their commercial introduction, even to the extent of 15 to 20 per cent, or all the way from 95 to 125 volts, which required electric lighting plants to be operated at different voltages because it was impossible to make all the lamps of the desired 110 volts.(3)

---

(2) Report on the Electric Light by Professor Henry Morton, Member of the Light House Board. Being the Appendix to the Annual Report of the Board for the year ending June 30, 1880. Washington: Government Printing Office, 1881. The report was docketed: Treasury Department, Document No. 100. *Light House Board.*

A few of the horseshoe lamps are still preserved, one of which is illustrated in Fig. 1. The broken-off piece of filament is seen at the bottom of the bulb neck where it joins the lamp stem, through the top of which platinum leading-in wires are sealed, with little platinum screw-clamps at their upper ends serving to support and make electrical connection with the filament. The lamp is mounted on a replica of one of the wooden stands commonly used to support lamps under test on the laboratory tables. The lamp stem extends downward into the stand about 1¾ in. These stands were wont to vary considerably in design according to the fancy of the wood-turner at the moment.

The electrical connections are completed by spirally winding the platinum leading-in wires around larger copper wires going to the binding posts. The glass parts are of lead glass. The bulb was blown from one-inch tubing and, in the lamp here shown, is $2\frac{5}{16}$ in. in diameter. The lamp stem was formed from three-eighth-in. tubing. The total height of such 16-c.p. lamps, called "A" lamps, in their final development was about 6¼ in.(4)

In March, 1880, the writer had occasion, at Edison's instance, to figure out certain candle-power characteristics of horseshoe lamps, and in connection therewith, took red ink impressions of the steel cutting molds by means of which the bristol-board filament blanks were cut out by hand with a paring knife, and also made blueprints of the carbonized filaments. These blueprints and impressions are reproduced with accompanying inch scale in Fig. 2.

The molds were made in like halves, with the bristol-board screw-clamped between them; this left the cutout filament blank with a connecting piece at the base, which was trimmed off before carbonizing. The largest filaments in the illustration were for the "A" lamps of 16 candle-power nominal rating, as shown in Fig. 1. The filaments of intermediate size were for half-voltage "B" lamps of eight candle-power rating, primarily intended for use with two in series on a full voltage "A" lamp circuit; while the smallest filament was for four-candle lamps for use four in series. The lamps of less than standard full candle power were only tentatively tried out because in the rush of development there was no time then to do more with them. But the principle of using lamps of fractional voltage and candle power in series on a system of standard higher voltage and candle power, then established by Edison, was commercially applied on a considerable scale after introduction of the bamboo lamp.

By carbonization the bristol board shrank linearly in the ratio of 15 to 11. The length of the "A" carbon filament was 2.95 in.; face surface, 0.054 sq. in.; width, 18.33 mils; and thickness 4.77 mils. The length of the "B" filament was 1.92 in.; face surface, 0.0423 sq. in.; width, 22 mils and thickness 4.77 mils. The writer does not happen to have preserved from his Menlo Park days any substantial record of the four-candle lamp other than the blueprint impression of its filament shown in Fig. 2.

The economy of this first commercial lamp may today seem exceedingly low, amounting to about 4.9 watts per horizontal-face candle at 16 candle-power rating, with an average life of about 300 hr. as compared with the successively greater economies finally attained with the bamboo-carbon lamp, followed by the Gem metallized carbon filament lamp, culminating in the modern drawn-tungsten filament lamps, which for comparison represent an economy of better than one watt per equivalent horizontal candle in the Mazda B (vacuum) lamp, and from 8/10 to 3/10 watt in the Mazda C (gas-filled) lamp, depending upon its candle-power size, all coupled with an increase in rated life to 1000 hr.

Nevertheless, in the brilliant light of today's achievements in improving upon the first commercial lamp our hindsight must not be so dimmed thereby as to prevent an acute and lasting perception of the fact that Edison's horseshoe lamp with its carbonized bristol-board filament was the original sprout from the seed sown by his discovery and invention of October 21, 1879, which demonstrated that the seed had commercial life, and started its growth and spread throughout the world.

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(3) "History of the Incandescent Lamp," by John W. Howell and Henry Schroeder, General Electric Co., Schenectady, N. Y., 1927, p. 78.

(4) An outline drawing of the lamp in exact size, minus small details, was published in *Scribner's Monthly*, February, 1880, in an article on "Edison's Electric Light," by Francis R. Upton, one of Edison's assistants at the time.

Electrified Factories in the Countryside

Power transmission will make a reality of the workingman's dream of a home in the country with a garden, chickens and plenty of fresh air for the children, predicted Alex Dow, famous pioneer of the power industry and president of the Detroit Edison Company.

"As power transmission develops," he said, "the small manufacturer and even large industries will carry their factories and business to the source of production or to the cheapest land. This means the workingman will follow his work to the smaller villages, where it will be possible for him to enjoy the things denied him in a congested city."

Inspection and Testing of Transformer Oil

By **O. S. HOCKADAY** and **D. B. McDONALD**
Transmission Superintendent **Transformer Specialist**
Texas Power and Light Company, Dallas, Texas

The Transmission Superintendent and the Transformer Specialist of the Texas Power and Light Company have written for us this detailed description of their transformer oil inspection and testing service. To keep transformer oil in good condition is so essential that we trust many of our readers in the field of operation will find special value in this contribution.—EDITOR

IN almost all of the 300 banks of oil-immersed high-voltage transformers in service throughout the six divisions of our central system and outlying districts, General Electric No. 10-C Transil oil is used as the cooling and insulating medium. From operations extending over a period of fifteen years it has been found that in order to keep the oil in these transformers in the very best condition, and to detect, and remedy, any faults that would or might cause damage or failure of any equipment at a subsequent time, a regular and periodic testing of the oil is necessary.

On account of the scattered territory which our company serves, the majority of our transformers are rather small, ranging in size from 25 to 8333 kv-a. and in voltage from 22,000 to 132,000 volts, and as a rule are single phase. For convenience of oil testing, all transformers in sizes under 300 kv-a. are put in one class and those of 300 kv-a. and above in another. A regular maintenance schedule for all classes of equipment has been made up, and is rigidly adhered to at all times. This schedule provides that from all transformers under 300 kv-a. in size oil samples are to be taken, and tested, once every twenty-six weeks, or twice a year; and from all transformers 300 kv-a. and above, oil samples are to be taken and tested every thirteen weeks, or four times a year. Care is taken to see that at every substation oil samples are secured from all of the transformers in service of the kv-a. rating called for, from all those transformers that are spares and of the correct kv-a. rating, and from such transformers as may be surplus and of the proper size. By spare transformers is meant those which are interchangeable with ones of a bank or banks that are in service, and which are kept on hand to replace a transformer that might fail, or one that is to be cut out of service for overhaul. By surplus transformers is meant those which have been removed from service and either left or stored at a substation or near it temporarily or permanently, until they are needed elsewhere.

Operating conditions in our company have proved to us that this plan of periodic testing enables us to keep our transformers in good operating condition and, at the same time, does not work a hardship in having samples taken too often or entail more work than necessary. The voltage rating of a transformer does not determine how often oil samples are to be taken from that transformer, as all of our transformer oil must stand a minimum of 22,000 volts as tested between brass, or copper, circular disk electrodes one inch in diameter, square on the edge, and spaced 1/10 inch apart. In addition, any transformer shift from one station to another, or any installation of new transformers, calls for the taking and testing of oil samples before the transformers are put in service, to assure us that the equipment is in the best of condition. Also, all repair jobs of any nature obviously demand that the oil be reconditioned at the time of repair if necessary.

To assure uniformity of testing and accuracy as to results, standard equipment has been provided for the taking of oil samples, and at two places over the system standard General Electric oil testing sets have been set up to test samples. Oil samples are taken in fourteen-ounce flint-glass bottles. The caps for these bottles are "Kork N Seal Caps" with a cork lining. The fourteen-ounce bottle is large enough to hold oil for two tests. The cases in which these bottles are shipped are of two sizes, twelve and twenty-four bottle capacity, and were made of cottonwood and black gum wood by a local boxing corporation. Figs. 1 and 2 show the two different size cases. Each box, or case, is painted red, stenciled "Texas Power & Light Company—Power Department" and has a hinged top with a hasp and snap. Each compartment is lined with corrugated pasteboard to lessen the danger of breakage in shipping. In order to have every bottle labeled correctly in the field, a form of sticker (see Fig. 3) was made up showing the station, date, transformer number and voltage, and the person who took the sample; and a sufficient number of these stickers is always enclosed in each box before shipment to label each bottle. These labels are always filled in, either with an indelible pencil or ink to insure legibility.

One of the oil testing sets is of very recent design, rated 30 kv., equipped with a 1-kv-a. induction voltage regulator, voltmeter coil and voltmeter, oil test cup, and air circuit breaker, as shown in Fig. 4. The other testing set, rated 50 kv., is of older design and is provided with a water-rheostat control.

The maintenance schedules of the different divisions are so arranged that the taking of oil samples in one district will not conflict with that in another, thus permitting a minimum outlay in testing equipment and material, such as bottles, cases, etc. In order to divide further the burden of testing, the samples from three divisions are sent to one station for testing, and three to the other.

The same care is exercised in preparing the oil bottles for shipment as is observed in the taking and the testing of the sample itself. The bottles to be washed are placed in a suitable container, usually a galvanized iron tub, and covered with water; and for approximately every thirty-six bottles in soak one seven-ounce box of "Gold Dust Washing Powder" is added. The whole is set over a gas burner and heated to just below the boiling point. When this point has been reached, the bottles are thoroughly washed. When they are clean they are then transferred to a clean warm water bath and rinsed several times, after which they are placed on a wooden rack, neck down, to drain. This draining process usually takes about one and one-half hours. After the bottles have drained about an hour, they are shaken slightly to get rid of the drop of water which usually collects at the end of the bottle. After the bottles have been drained sufficiently, they are placed on another rack in a drying oven, side by side, but with the neck of the bottle up, and allowed to dry for approximately two to four hours at a temperature of about 60 deg. centigrade. A view of one of the drain racks and drying oven is shown in Fig. 5. The caps of the bottles are also placed in the drying oven along with the bottles and allowed to dry also, thus eliminating any moisture that might be in the cork liner. When the drying period is over, the bottles are removed, immediately capped, and the cap dipped in melted paraffin to seal the bottles. The bottles are then crated, tagged, and shipped out to the different patrol districts, or else stored in a dry place, ready for shipment.

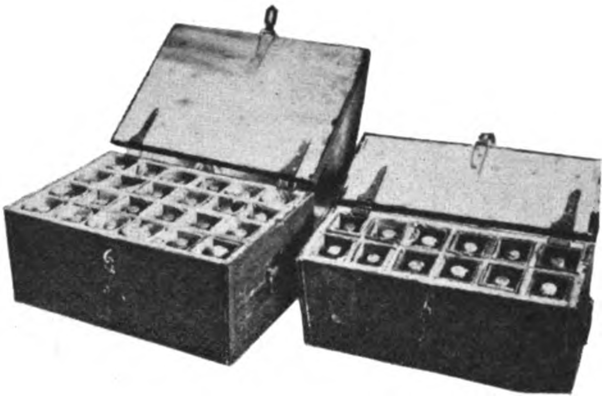


Fig. 1. Transformer Oil Sample Bottles in Twelve and Twenty-four-bottle Cases. Notice that each bottle is protected against breakage by pasteboard. The boxes have a hinged top, with hasp and snap

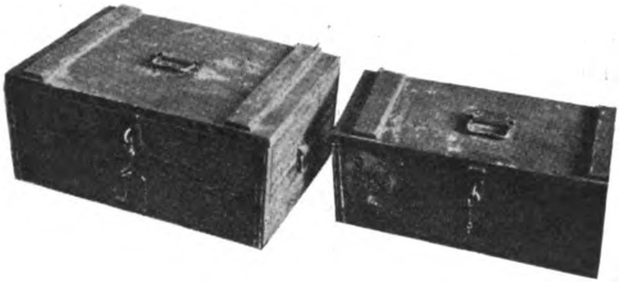
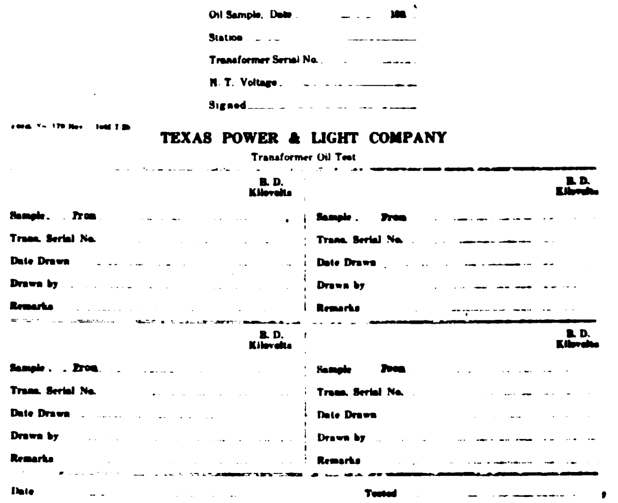


Fig. 2. View of Oil Sample Bottle Cases, Ready for Shipment

The problem of securing good oil samples cannot be stressed too much, nor can too much care be used in the taking of them. One requisite is that the bottles used for the samples should be clean and dry. The method here outlined gives assurance of this condition.



Oil Sample, Date 192

Station

Transformer Serial No.

H. T. Voltage

Signed

TEXAS POWER & LIGHT COMPANY

Transformer Oil Test

B. D. Kilovolts

Sample. From

Trans. Serial No.

Date Drawn

Drawn by

Remarks

B. D. Kilovolts

Sample. From

Trans. Serial No.

Date Drawn

Drawn by

Remarks

B. D. Kilovolts

Sample. From

Trans. Serial No.

Date Drawn

Drawn by

Remarks

B. D. Kilovolts

Sample From

Trans. Serial No.

Date Drawn

Drawn by

Remarks

Date Tested

Fig. 3. (*Above*): Form Used in Labeling Sampling Bottles. (*Below*): Multiple Form Used in Recording the Tests of Samples

The next requisite is that the sample taken be representative of the oil at the bottom of the tank. All of our high-voltage transformers are equipped with ¼-inch sampling tubes, pipes, or "goose-necks" with a cap on the end. In some cases, this ¼-inch pipe taps the two-inch drain outlet between the tank and the main valve of the tank, while in others it is connected externally to the main base valve of the transformer. Where transformer bases are high enough to allow the oil sample bottle to be placed under the ¼-inch valve, no sampling tube is necessary. Our method in securing the oil samples is to drain off enough oil before the sample is taken to assure us that all of the oil which was stored in the sampling pipe has been flushed out and any sediment that might have been lodged in the pipe has been removed. Filling a fourteen-ounce bottle twice and throwing the oil away is usually sufficient. The sample is then taken in a second clean, dry bottle to eliminate any contamination that might come from the oil stored in the sampling tube. If there is any doubt about whether the bottle used in taking the sample is dry, the added precaution is adopted of rinsing it out with oil from the bottom of the transformer before the final filling.

After the oil sample has been secured, the bottle is capped, labeled with a sticker properly made out, and as soon as possible is sealed again with melted paraffin, after which the cases are shipped by express to a designated testing station.

The method followed in the testing of oil samples at the two testing stations is that given in the instructions furnished by the manufacturer of the testing sets. The test cups on each of the two sets are provided with circular disk electrodes, one inch in diameter, spaced 1/10 inch apart, and kept at that distance by the use of a thickness gauge supplied with the set. The temperature of the oil sample before being tested is raised to at least five degrees centigrade above the room temperature, before opening the bottle, to prevent any condensation of moisture from the air on the surface of the oil sample. For this purpose, either a small electric heater, or a drying oven where several bottles are warmed up at a time, is employed. Before the bottle is uncapped, a test for free water is made by inverting the sample suddenly and looking for globules of water dropping to the bottom.

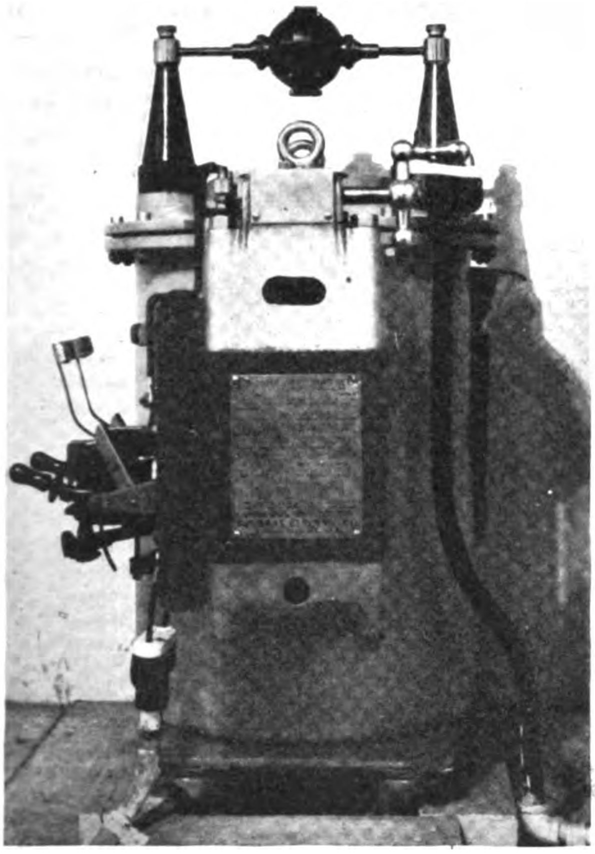


Fig. 4. Front View of General Electric 30-kv. Oil-testing Set

The general condition of the oil as to color and sediment is noted and recorded under the "Remarks" column on the regular form supplied for this purpose. One of these forms is shown in Fig. 3. Space is provided on this form for tests from four bottles. After the temperature of the oil sample is correct, some of the oil is used to rinse out the testing cup once or twice, and the spacing checked. After this has been done, the test cup is filled with oil to the top, and the cup gently agitated to remove any air bubbles in the oil. Voltage is then applied at a uniform rate of approximately 3000 volts per second until a break-down occurs across the gap, at which time the applied voltage is removed so as to prevent any unnecessary fouling or carbonizing of the electrodes and oil. After the break-down the test cup is agitated again to loosen any carbon on the electrodes, and a second test is then made. This is repeated five times, and the average of the five "shots" recorded as one test on the regular form under the column marked "Break-down Kilovolts." As the amount of oil necessary to fill the test cup is only about one-half of the oil in a fourteen-ounce bottle, the test cup is emptied after five tests, the gap checked, the cup rinsed out, and then refilled with the rest of the sample, and the operation repeated for a second set of five tests, the average of which is recorded under the other value on the form provided. This gives two tests as a result of ten breakdowns and should be a fairly accurate test of the condition of the oil.

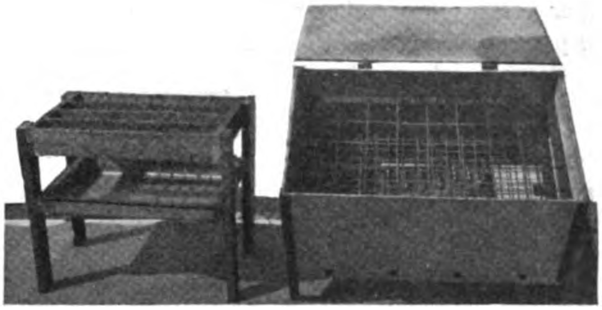


Fig. 5. Oil Bottle Drain Rack on the Left, with Bottle Drying Oven on the Right. The drying oven has a stove element at the bottom of it for source of heat, and is equipped with a three-heat switch

Any oil that tests below 22 kv. with 1/10-inch gaps is questionable, and a check sample is always taken and tested. In most cases, these check tests are made in the field at the apparatus in question by means of one of the General Electric portable 30-kv. 50-140 cycle oil testing sets, which is light enough for portability, easy to set up, and simple to operate. If the check sample still tests too low, arrangements are made and the oil filtered. Our filtering equipment consists entirely of General Electric seven-inch, ten-gallons-a-minute paper presses, since we do not carry any large amount of oil in storage, nor do we have to recondition oil in any appreciable amounts.

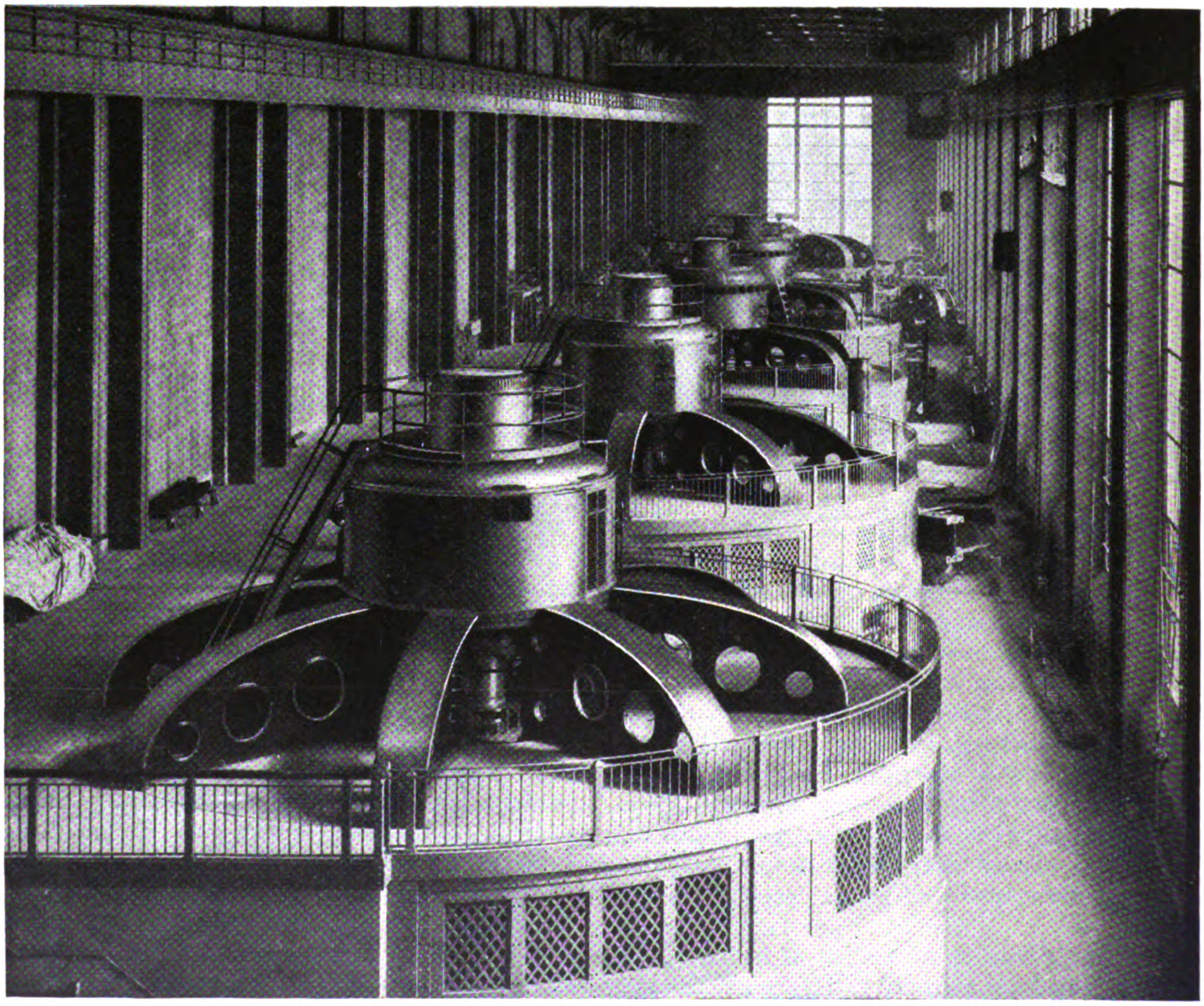
Any oil that is reported as being very dark in color, or as having a large amount of sediment in it, requires a more frequent inspection and testing than is normally necessary to show whether the oil is nearing the end of its useful life; and in case a considerable deposit of sediment and sludge is found on a transformer core and coils during inspection, the oil is reconditioned, or replaced with new oil.

By such systematic and periodic inspection of transformer equipment, we have been able to keep our apparatus in very good operating condition. Once a week, the oil level in all high-voltage transformers is noted and corrected, if necesssary. Every four years, as part of our regular maintenance, the core and coils of each open-type transformer (without conservator) are lifted for an inspection and general overhauling, and the oil is filtered. The method followed in filtering is not to circulate the oil out of the transformer tank at the bottom and into the tank at the top; but instead all of the oil is pumped out to some exterior container, and then is pumped back into the main tank which means that all of the oil has passed through the filter press twice. In connection with the filter paper press, an electric drying oven is used to keep the paper dry, in order to get the best results. At the end of the second year after each general overhauling, every open type transformer is again taken out of service, the coils and core washed down with oil under pressure, and the oil is filtered. Thus the oil in all of our open type transformers is filtered every two years, and the transformer completely overhauled every four years.

On account of our limited operating experience with conservator type of transformers, we have not set up a regular maintenance schedule for them; but since the purpose of the conservator is not only to maintain the dielectric strength of the oil, but also to lessen sludging, it appears that filtering and overhaul of conservator transformers should not be as frequent as in open type transformers.

To date, our periodic testing and filtering of oil that we carry out on transformers have proved of much benefit to us, and the number of transformer failures we have had, and the expenses incident thereto, have been materially reduced.

The Conowingo Generators



This remarkable station of the Philadelphia Electric Company will contain seven generators in all, four of which have been installed by the General Electric Company. Each of these units is of 40,000-kv-a. rating and of welded and fabricated steel construction

Operations in the Oil Fields

Introductory Survey of Conditions—Cable Tool Drilling—Rotary Drilling—Power Requirements—Refining and Transportation—Electricity in the Petroleum Industry

By R. H. ROGERS
Industrial Engineering Department, General Electric Company

THE petroleum industry is the second largest industry in the United States, being exceeded in extent only by agriculture. It utilizes an investment of eleven billion dollars and gives employment to over two million people. The year 1929 will require the production of a billion barrels of crude oil. This industry is peculiar in that it has no control over its raw material, which must be taken largely when and where it is found. At this time crude oil is accumulating faster than it can be used; that is why we are enjoying gasoline at a low price. The qualities of crude vary greatly—for instance, the specific gravity runs from 14 deg. to 44 deg. Baumé; gasoline content from 2 per cent to 52 per cent; and the price at the wells ranges from 50 cents to $1.44 per barrel, with an average of about $1.10. Some special crudes bring over $4.00 per barrel.

The United States produces and uses 72 per cent of the world's supply of oil. Texas, Oklahoma and California produce 75 per cent of our crude. Twelve other states produce the other 25 per cent with Pennsylvania, the original producer, contributing only one per cent. Among foreign countries, Mexico, Venezuela, Russia, and Persia are the leaders in the production of petroleum, with about two dozen others adding small amounts.

In this country there are 760,000 wells, of which 360,000 are producers, running from 100,000 barrels per day to a single barrel per day, with an average of less than eight barrels per day. Three per cent of the wells produce 50 per cent of the crude. Production in new fields declines rapidly, averaging 80 per cent fall-off after 3 years. This necessitates the annual drilling of 20,000 new wells, of which over 6000 are dry. Our deepest well is 1⅗ miles deep; and there are thousands of wells whose depths are in the neighborhood of a mile.

Crude oil is generally believed to be of organic origin, as is coal. It is probably a residue from millions of living things of low order, animal and vegetable. It is found in layers of sand and porous rock of sedimentary origin at all depths so far explored, and over great areas, the boundaries of which are unknown. As the saying is, "Oil is where it is found." Oil is found impregnated with gas in liquid form in a manner similar to charged water, ginger ale, and the like, sometimes with chambers of free gas above, but under high compression. Salt water is an ever-present hoodoo which follows up from underneath whenever the pressure is sufficiently relieved. The oil may be in lens-shaped sand beds or in apparently meandering streams in sand flats with dry islands interspersed, much as they occur in sluggish streams in broad, flat valleys. When a well taps a pool the gas expands and forces the oil to the surface for what is called flush production. Unless carefully conserved, the flush production quickly stops and some form of pumping must be used. This stage is called settled production and may last in diminishing rate for many years. It is an interesting fact that present methods only bring up from 15 to 20 per cent of the oil actually underlying a given acreage, because much of the oil adheres to the sand particles and free oil may be taken only from the voids between the grains. The sand varies in density, grain formation, and rock pressure, so that percentages of recovery vary greatly; and diverse means are required to get maximum yield under different circumstances.

New fields and the limits of existing fields are discovered by means of wild-cat wells. These are wells drilled at great expense, usually far from the beaten paths and, being discovery wells, some 17 out of 20 of them are dry holes or "dusters." Geologists, armed with various types of exploring devices, assist in finding likely locations. Shallow core drilling to certain indicating strata also serves to fix locations. However, the majority of producing areas are found by practically blind drilling, following "hunches" or by accident.

Steam and gas engine power and electricity are all used in oil field work. In any case, quantities of water are required, the provision of which frequently becomes a serious matter. Often four water wells are drilled to make possible the drilling of one oil well. Sometimes water is pumped as far as 18 miles from a stream to a well. Electric power companies seem to be imbued with the gambling spirit that pervades the oil fields and they extend lines or build entire new systems to supply power to fields of unknown life and unknown power demand. Most wells are drilled by contractors, but many large companies have their own drilling forces.

Oil fields usually appear in regions which are at first relatively inaccessible. The necessity of providing some 300 tons of rig at a drilling site is a formidable task. Because of the fact that electricity makes possible the application of motive power in lightweight and portable units, it proves to be a great utility; and because of the economy which

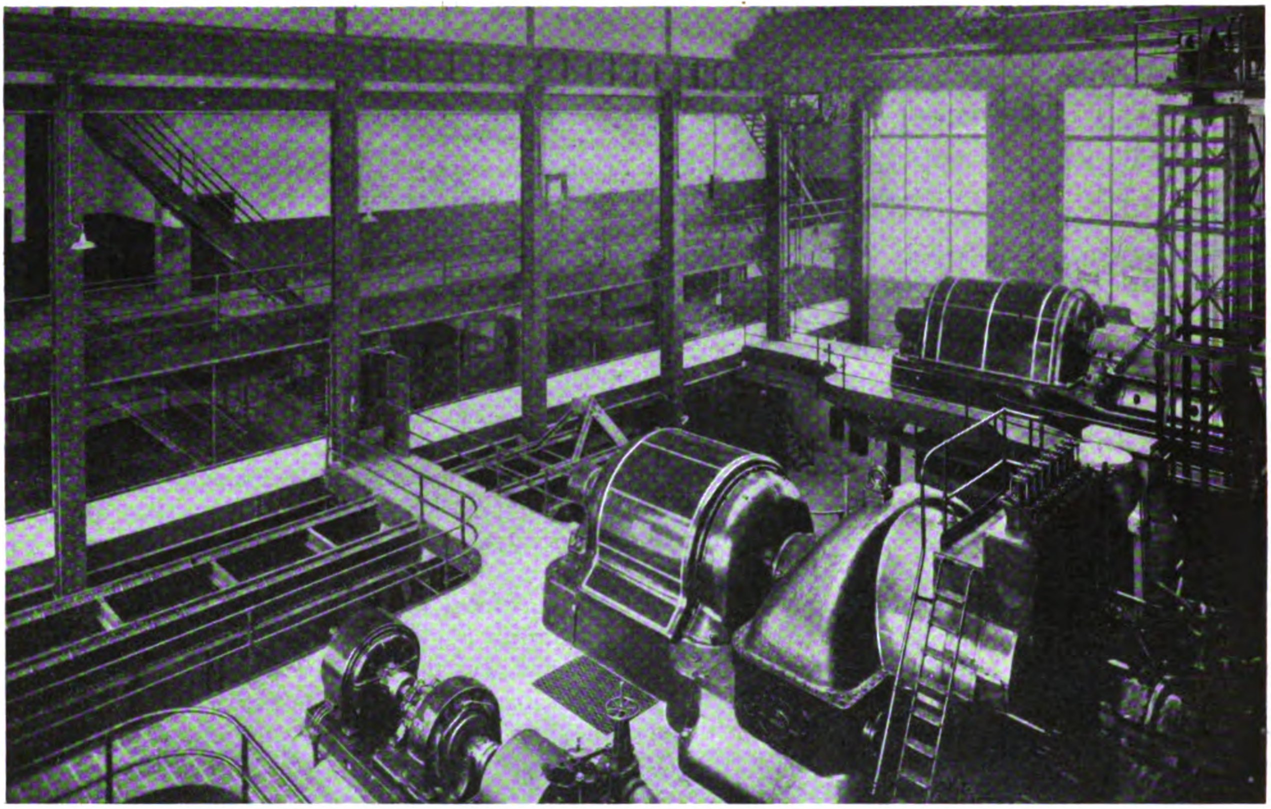


Fig. 1. A 15,000-kw. and a 7,500-kw. Generating Unit in a Power Station Whose Major Load is Utilized in Oil-field Operations

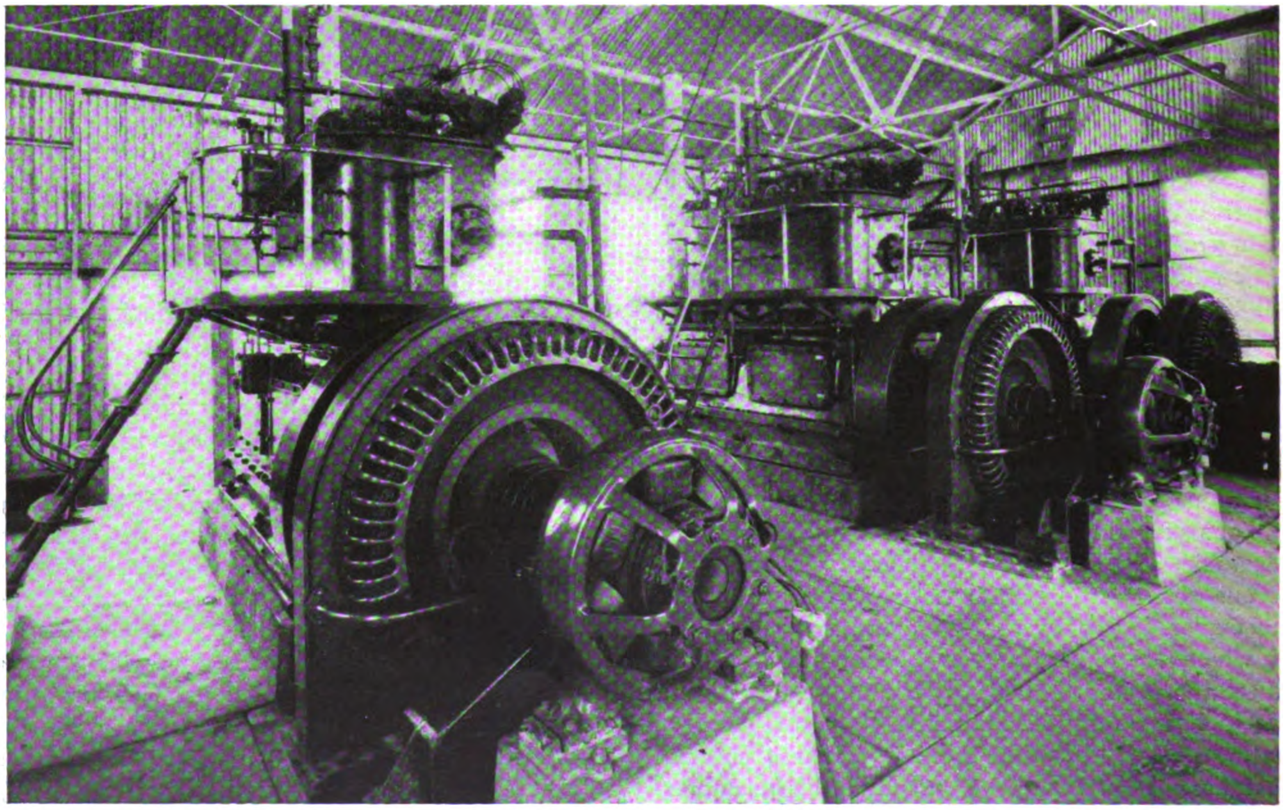


Fig. 2. Three of Four Gas-engine-driven Generators of 156-kv-a. Rating at 480 Volts and 257 r.p.m. Now in Use for Supplying Auxiliary Power in a Gasoline Plant

accompanies its employment, electric power has been successful in the oil fields. Throughout the course of the development of an oil field electricity plays an important part. In the early establishment, it is applicable to drilling operations; later it is employed in pumping, processing, and transportation. Furthermore, as an adjunct to the building up of the community of an oil field, electricity enters and holds its place as a necessity.

Wells may be drilled by cable tools or by rotary tools, or, as is often the case, by both. Cable tools pulverize the rock by successive blows as the cable is jerked up and down by the drill rig. Rotary tools act by grinding, and cutting after the manner of ordinary machine-shop drills. Cable-tool drilling requires a derrick about 80 ft. high, a winch for hauling out a tool string and for handling casing. A crank and walking beam convert rotating motion to reciprocating motion. The power may be a motor, a gas engine or a steam engine with a battery of boilers. Drilling is done in the dry, except for a barrel or so of water in the bottom of the hole to take up the drillings. The beam makes 30 to 40 oscillations per minute and the stroke is adjustable, but 24 in. is the commonly used stroke. The speed must vary with different parts of the stroke cycle and the strokes per minute must be accurately adjustable. The reason for these variables is that the long cable is elastic and unless timed just right, the tool itself might never leave the bottom of the hole. On the other hand, when timed right, the drill string (perhaps 40 ft. long and weighing a ton or more) will jump up and down 30 ft. with only a 2-ft. stroke at the top. This long stroke action strikes a vicious blow and does good execution. The routine is to drill about four hours; then the walking beam is disconnected from the power, a rope drive is put on the bull wheel, the temper screw is unhooked from the cable, and the tool string is hauled up. This may take 12 to 20 minutes. The bailer, a long tube with a valve in the bottom, is let down on a small line from a separate sand reel and the mud is brought up and run out into the launder. Several bailer trips may be required. Samples of the cuttings are kept for reference. In the meantime, a resharpened drill has been put on and the string is let down in preparation for another round of drilling. The drill may be off the bottom about an hour. Numerous troubles develop, such as a jamming of the drill in a rock hole, or alongside a loose boulder, or worse yet, by a new and larger drill jamming in a tapered hole made by the preceding dull drill. The cable may part or the tool string may break. These accidents lead to a long series of fishing operations and may cause abandonment of the well. The hole is more or less crooked because the various strata encountered vary in density and angle. The long bailer may jam going past a bend. Various reaming tools are used to enlarge the bore at such places. Casing must follow the drill closely to prevent caving in and to keep out water. From time to time the drill is reduced in diameter as the well deepens; then a string of casing of the new size must be run all the way from the top. Hence there may be for a good part of the way four concentric casings. Great care has to be taken to detect traces of oil or gas and precautions are necessary to prevent a blowout, should a high-pressure area be penetrated. Wells are no longer allowed to "gush"; though accidents will happen, and much waste still results from gas blowouts and fires.

In the electrically-equipped cable rigs, motors of 50 or 75 hp. at speeds of 720 or 900 r.p.m. are commonly used. These motors are of the wound-rotor type, because they are thus capable of being operated at speeds lower than their normal rated speeds, and it is possible to effect speed control through varying secondary resistances. The motor is applied to drilling operations through belt or gear reduction, the ordinary speed of the drilling crank being 20 to 45 r.p.m. with a maximum of some 65 or 70 r.p.m.

There is in use at present a very efficient drill rig motor and control which meets cable tool requirements. Two drum controllers are used, one providing a coarse adjustment and the other a fine adjustment which is used over and over as the coarse setting is changed. This, in effect, gives about 55 speeds to the walking beam. The presence of resistance in the secondary circuit of the motor causes it to slow down and speed up with the lifting and dropping of the drill string, so that full advantage is taken of the "spring of the line."

Rotary drilling involves larger crews, more power, higher drilling speeds, higher derricks and no casing until the well is nearly completed. The effect of the casing is obtained by pumping heavy viscous mud into the hole under high pressure which, together with the great static head, effectively seals up the walls of the hole. The drill is screwed on to the end of a drill pipe, the top section of which is a square bar called the "Kelly." A square hole in the rotary drill table serves to rotate the drill pipe and drill. The mud circulates down the drill pipe, through the drill and up again to the surface. It then flows through open ponds and back to the pumps for recirculation. The drill is withdrawn by means of a winch and a six or eight-part tackle. The pipe is disjointed at every fourth joint and these sections, called fourbles, are stacked up inside the derrick. A period of four to six hours is required to bring up the drill from a mile deep. After the drill is fixed up, the process is repeated in reverse until the mile of pipe is down and the Kelly is again in the square hole ready for driving. The deeper the hole, the greater proportion of time is the drill off bottom.

The drill pipe, of four- or five-inch diameter, weighs 25 lb. per ft. and is veryelastic. When the drill jams,

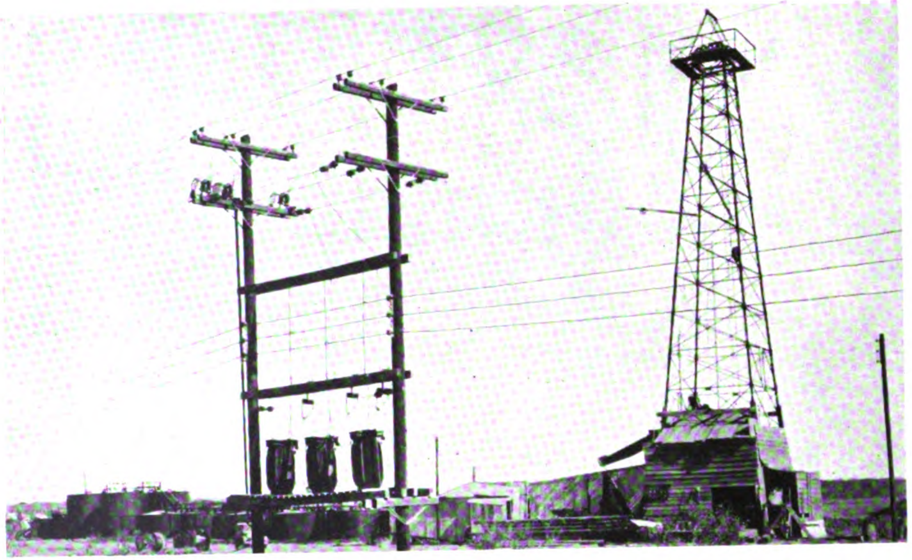


Fig. 3. A Typical Well in an Electrified Section of the Oil Fields Showing Transmission Lines and Equipment Utilized in a Cable-tool Rig for Well Drilling

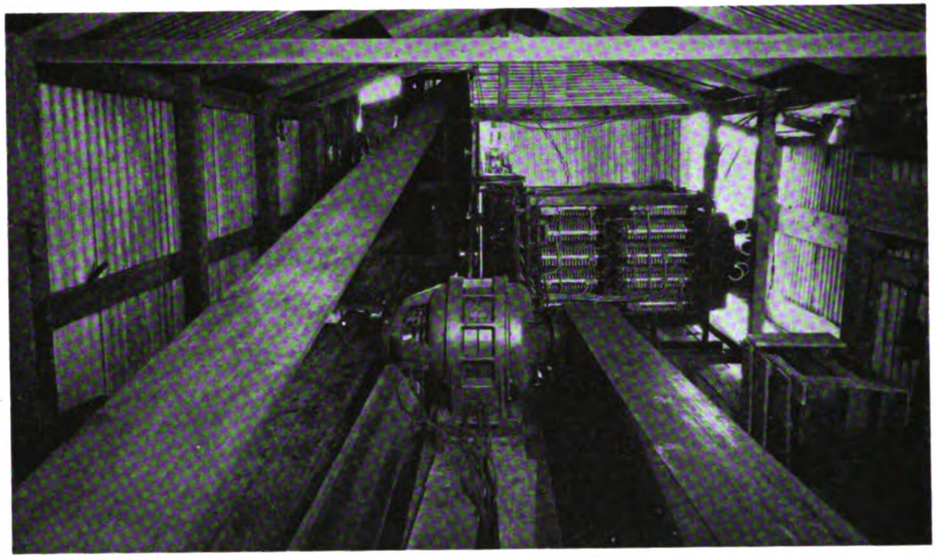


Fig. 4. The Interior of the Well Building Shown in Fig. 3. By Means of this cable-tool drilling equipment, a record run of 2950 ft. was made in 26 days

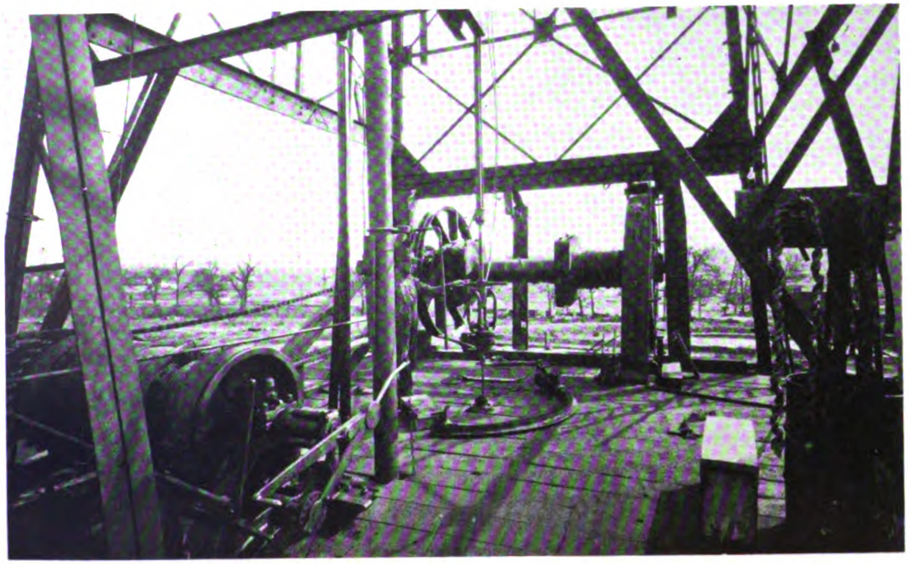


Fig. 5. Cleaning Out an Oil Well with Cable Tools Operated by a Two-speed 50/20-hp. 440-volt Oil-well Pumping Motor in an Oklahoma Oil Field

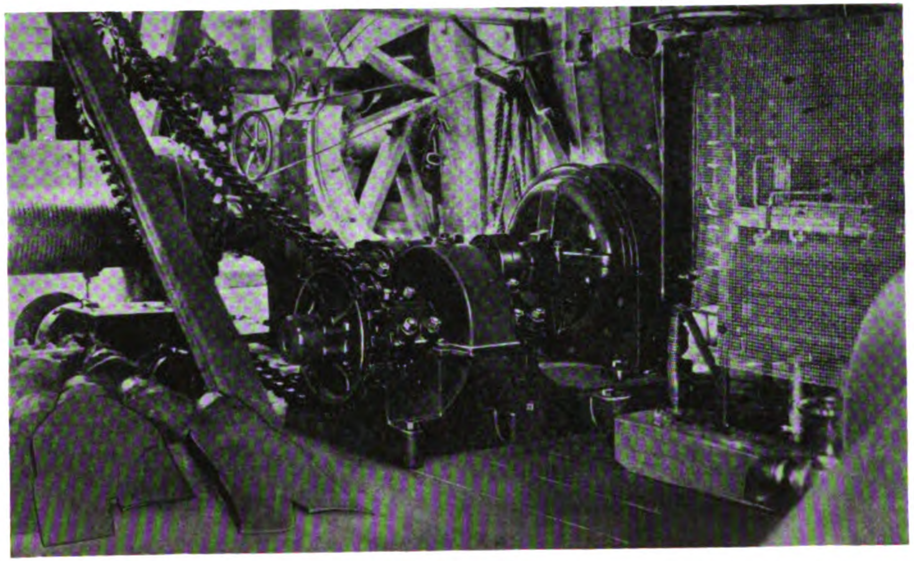


Fig. 6. A Ten-pole 75-hp. 720 r.p.m. 440-volt Motor with Reduction Gear for Driving a Typical Rotary Drilling Rig in a California Oil Field

the pipe at the top can be turned one or more turns each way without harm. When lifting, about 18 in. of pipe comes up at the top of the well before the drill comes off the bottom. Rotary-drilled holes are more crooked than cable-tool-drilled holes because they are forced harder, and there is no casing to true the hole; hence there is very little guide for the drill pipe. The lower 1500 ft. of the pipe rests its whole weight on the drill and, because of its flexibility, assumes an elongated cork-screw shape in the hole. The drill is fairly free to penetrate wherever the going is easiest; and the wonder is that the result is of any practical value. Tests have shown slants of as much as 45 deg. from the vertical. Such wells cause high operating costs and early abandonment if they are ever successfully completed. Rotary drilling troubles come from the drill jamming, breakage of the drill pipe, or twist-offs, as they are called. Long fishing jobs follow and the hole may have to be abandoned.

When it is considered that there is a pressure of 15 tons on a bit which is making 80 revolutions a minute on the end of a practically unguided flexible drill stem a mile or more in length, it is surprising indeed that it does not turn about and come up through the ground in some neighbor's dooryard. Before going into the pay sand, the rotary rig is taken away, a single casing is run in and the last few hundred feet are completed with a cable tool rig; otherwise, the hole might be pushed right through the pay sand without finding it.

The electrical equipment used in rotary drilling is largely similar to that used in cable-tool drilling; and in some instances a given outfit may be used in either method. In general, however, it may be said that the rotary rig employs heavier equipment, the motors being of 100 to 150 hp., and the control equipment capable of taking care of the heavy duty incident to reversals, stalling, and the like.

Having completed the drilling of a well which gives promise of paying production, there must be assembled an array of separator tanks, field storage tanks, surface piping and equipment for taking care of the oil. Often the outfit of tanks is filled only once before the well becomes unprofitable. At first, the well may flow from the internal gas pressure, but eventually it must be pumped. One method is by air or gas lift. This requires a battery of compressors which force air or gas down the tube to the bottom of the well where it mixes as a froth with the oil; which, thus lightened, rushes up to the surface between the tube and casing. Sometimes the route of the gas is reversed. The gas is now separated from the oil and is sent back down by the compressor. This process prolongs the heavy production period and makes for maximum ultimate recovery. Another similar method involves the repressuring of the oil sand through some centrally located key well. The gas follows through the sand and forces oil up the neighboring wells. Another form of pumping is termed swabbing. A heavy cylinder with outside packing and a single inside valve is lowered into the oil by a wire cable. When it has sunk into the oil a couple of hundred feet, the drum is reversed and the oil above the swab is hauled up to the surface. The swab fits the casing, so this might be termed an eight-inch pump with a mile stroke. Each stroke takes about 20 minutes unless the pumper attempts to withdraw more oil than he can lift. When this happens, he waits until enough gas accumulates under the swab to help lift the load.

The next stage is a straight pumping operation in which a tube is let down to the bottom of the well with a regular pump body on the end. There is a ball valve in the bottom and one in the piston, which is worked by a sucker rod from a walking beam at the rig. The rod is of ¾-in. round steel with heavy upset screw joints. The oil comes up the inside of the tube in this beam-pumping process, which may go on for many months or years. A low derrick serves for beam pumping and a winch handles the rod, tube, and pump when being taken in and out, and for replacing casing. Crooked wells impose heavy wear and tear on the rods, tubes, and casing. A two-speed motor may be very conveniently applied to this work, the low speed being used for pumping and the high speed for servicing the well. There are about 8000 such motors in the oil fields.

The last stage of well pumping, when production is low and intermittent, utilizes the band wheel power. This consists of a great horizontal pulley, 24 ft. in diameter, to which are bolted two eccentrics. Each eccentric causes a number of long rods to oscillate, and each rod in turn is attached to a pump jack at a well. The whole outfit resembles a huge spider with 1000-ft. legs, each leg slowly pulsating with life. At the jack, an open link connects the rod with the bell-crank and an attendant can slip this link out at any time to stop the pump. Some of the wells in one such group may be thus pumped continuously and others only an hour a day.

One feature of field operations as distinguished from the refining of oil is the recovery of natural gasoline. The gas coming from most wells is "wet" *i.e.*, it contains evaporated gasoline. Natural gasoline plants are established in localities where there are many wells; and it is their function to turn wet gas into dry gas and to make available high-test gasoline for mixing with low-test gasoline or for use by itself where very volatile gasoline is required. These plants usually have their own electric power stations in which are used a number of gas-engine-driven generators. The process requires a great many motor-driven pumps and gas-engine-driven compressors. The process is this: Mineral seal oil, which is next below kerosene in fractional distillation, is brought from the refineries and is held in bubble towers in the form of a froth, like shaving

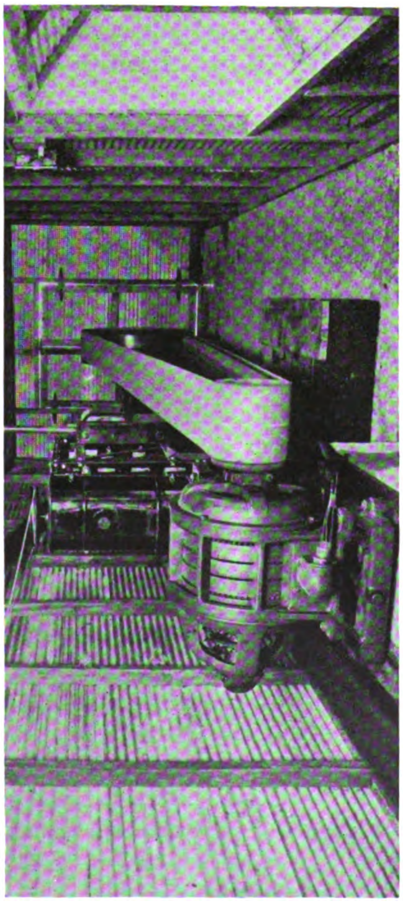


Fig. 7. The Oil Well Pumping Equipment for a Well in the Course of Settled Production in a Texas Field. This is a typical interior view

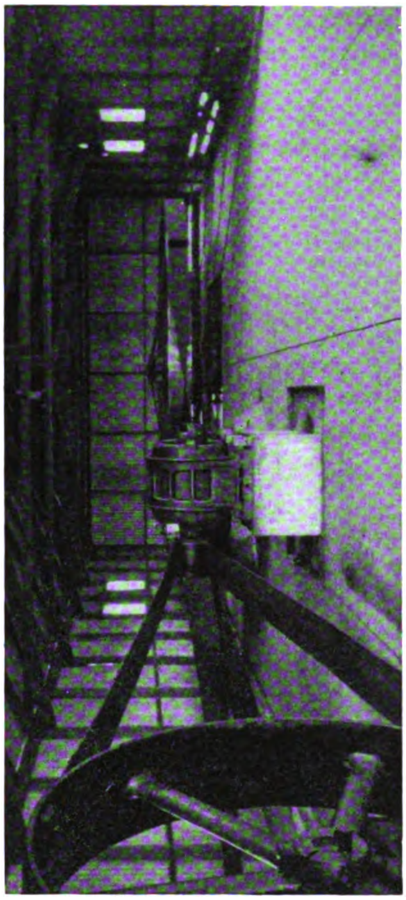


Fig. 8. Band Wheel Pumping, in which a 60-hp. Motor Supplies Power to 22 Wells. This method of pumping is applied in the later stages of oil production

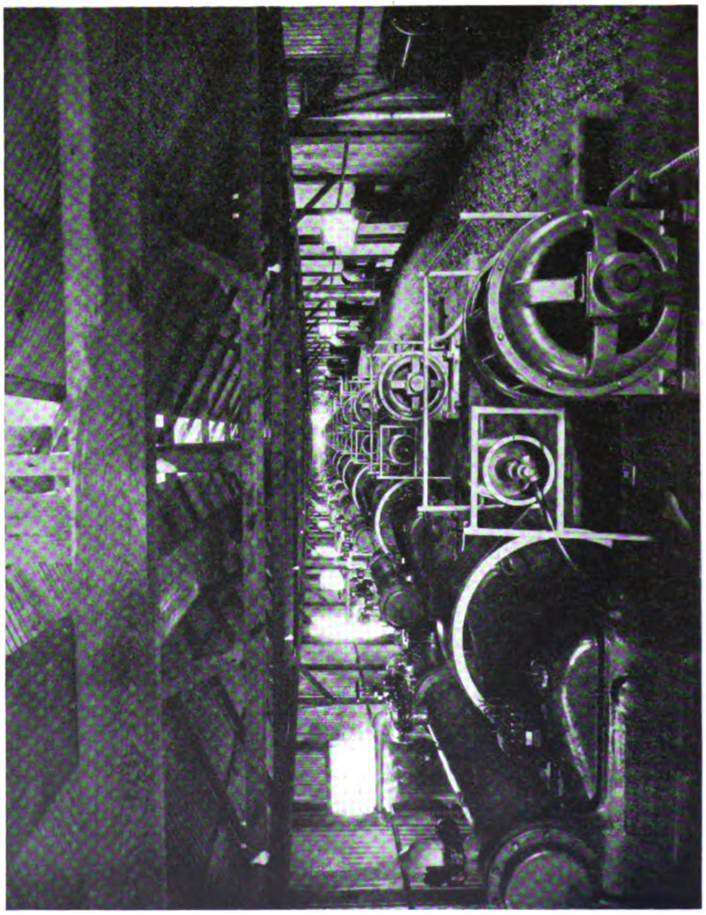


Fig. 9. Twenty-four 75-hp. Motors Driving Air Compressors for Air-gas Lift in Oil Production. Small units are thus used in large groups to gain portability

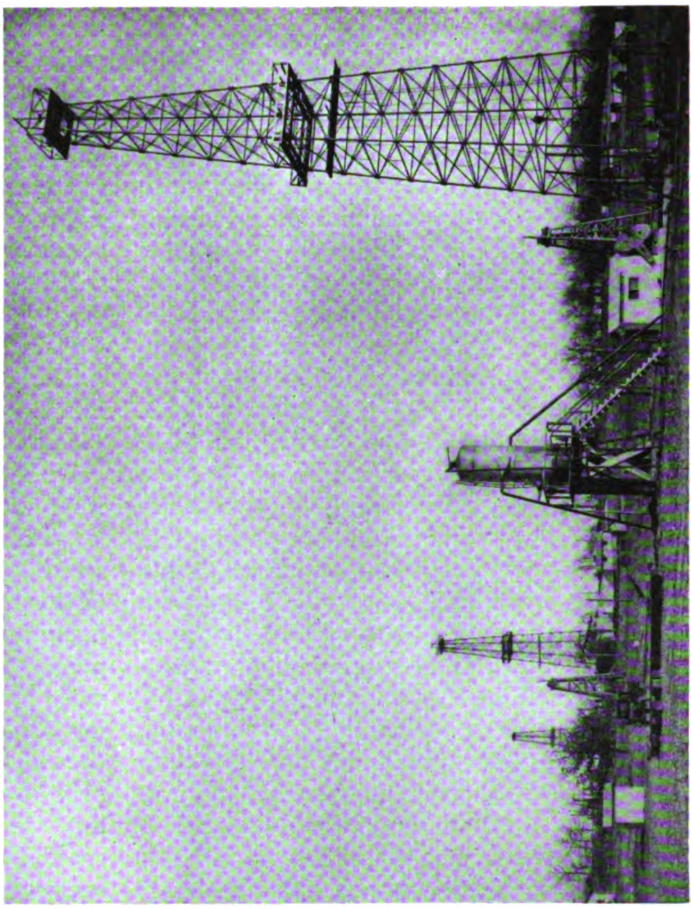


Fig. 10. An Oil Well in the Stage of Settled Production, which Sometimes Continues for Months. Here pumping is carried on by means of a two-speed 50/20-hp. 440-volt motor

lather. The wet gas is blown through these bubbles; and practically every particle of gasoline vapor is absorbed by the mineral seal oil. The charged oil is sent to stills, where it is heated and the gasoline is driven off to condensers, and thence to storage tanks. The mineral seal oil is again sent to the bubble towers to repeat the cycle. Natural gasoline forms from 10 to 12 per cent of our motor gasoline and higher proportions of aviation gas and other very volatile fuels.

Crude oil from the lease tanks is collected by gathering pumps into intermediate field tanks; and from there it is collected in great quantities on tank farms where large areas are covered by tanks, each of which may hold half a million barrels. From these tank farms lead the numerous pipe line systems of the country. They go to shipping points or refinery centers hundreds of miles away. There are now nearly a hundred thousand miles of these pipe lines, equal to one-third of the total railroad mileage of the country. The burden of oil carried in this way in a year would fill a tank car train 40,000 miles long. They work efficiently at from 4 to 10 cents per mile per hundred barrels, or less than one-tenth of the cost of railroad haulage. Much of the oil refined on the Atlantic Coast is piped 2000 miles from Texas fields.

At any one time there are 17 million barrels of oil in transit in the pipes, moving at about four miles per hour. A great amount of power is required by the pumping stations which are spaced from 20 to 50 miles apart along the lines. Until recently, reciprocating pumps were used exclusively. These are ponderous, slow-speed machines, requiring much gearing to accommodate comparatively high-speed motors. Now the trend is largely toward high-speed direct-connected centrifugal pumps with motors up to 1000 hp., and up to 3600 r.p.m. in sizes of, say, 350 hp. Induction motors of both wound-rotor and squirrel-cage types, as well as synchronous motors, are used in this pumping service. Electric pumping stations require fewer attendants and less or no tankage; for it is believed that these centrifugals can be shut down without materially choking the flow of oil through them, whereas a reciprocating pump stopped is an absolute block to the flow of oil. Hence, large oil tanks are provided at reciprocating stations to hold the oncoming oil until the pump in trouble can be cut back into the line. Pipe lines sometimes gradually clog up with wax or paraffin and revolving turbine scrapers, called "go devils," are sent through the pipes periodically. They are driven ahead and revolved by the flow of oil. Farm dogs often hear one of these "go devils" scurrying along four feet or so under ground and will give chase at full yelp mile after mile, doubtless figuring that it must come up somewhere. Pipe line walkers patrol the lines, looking for evidences of leakage. Some of these men have been walking lines for 20 years.

Crude oil is an exceedingly complex mixture, blend, and compound of hydro-carbon combinations. From it are made hundreds of distinct products extremely useful in every phase of human life. At refineries the crude is separated into a few major divisions; in the laboratories certain fractions are reformed into hundreds of minor products.

Crude oil itself varies over a wide range in its make-up and, again, the products of the refineries vary widely to meet market conditions. The refiner always tries to arrange the percentages of the various products so as to get the most profit from a barrel of crude; and at best his net return is about 11 cents per barrel. About 1900, kerosene was in great demand in comparison with the total output of crude. Today gasoline is the most profitable factor.

High-test naphtha, gasoline, kerosene, fuel and gas oils, and lubricants are driven off in this order from the crude in stills by successive increases in temperature. These are called straight-run products, or fractions. The gasoline yield under this process averages about 12 per cent. A few years ago it was discovered that the heavier residue could be cracked by high pressure and temperature so as to recombine as gasoline, thus increasing greatly the yield of this product from material in which it did not even exist before. The gasoline yield now averages 39½ per cent. Motor gasoline is now made up of about 10 per cent natural gasoline, 30 per cent straight-run and 60 per cent cracked gasoline. These ratios vary greatly, as all the larger companies aim for a uniform product, though their crude may vary greatly from week to week. The smaller refinery companies, having limited throughput, produce gasoline of varying characteristics as they do not have sufficient choice of blends to hold constant quality.

The residue after distillation and cracking contains petroleum jelly or vaseline, paraffine, road oils, asphaltum, coke, etc. The paraffine is frozen out by refrigeration and the vaseline is extracted by centrifugals. Paraffine has largely replaced the vegetable chicle in chewing gum, and it has hundreds of other more essential uses.

The petroleum industry is basing 1929 production on the demand of 26,750,000 motor vehicles, each to consume 610 gallons of gasoline this year. A question often asked is, how can the oil supply last in the face of this demand for a billion barrels per year? It is a fact that estimates of oil in the ground each time exceed the preceding estimates and, in the meantime, nearly as much as the estimated total is taken from the ground. New fields are being discovered. Deeper drilling has reopened many otherwise dead fields. Better refining methods have served to conserve the crude. New and better methods of recovery will bring up more than the 20 per cent now available, so that old fields will eventually be reworked. Crude oil is cheaper and more plentiful

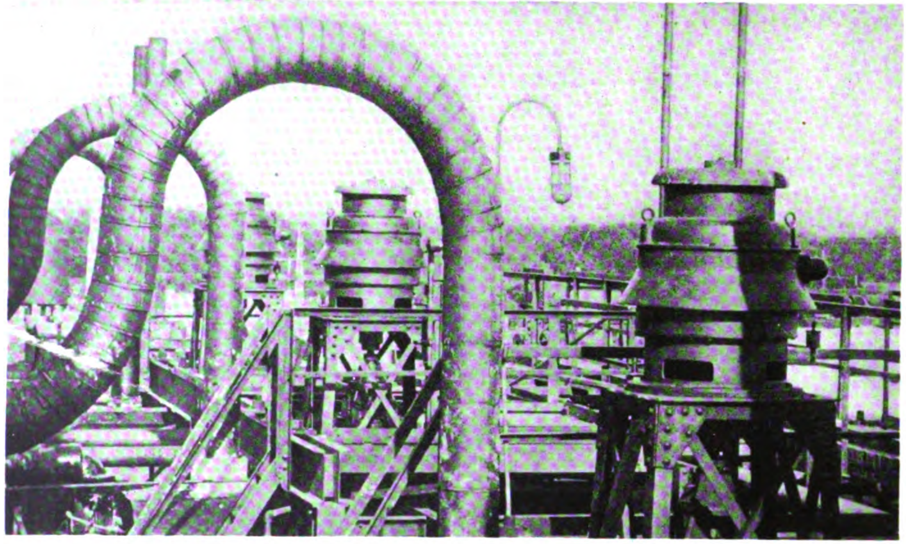


Fig. 11. Three 35-hp. Vertical Motors Installed Outdoors for Driving Circulating Impellers in the Oil-cracking Process at an Oil Refinery

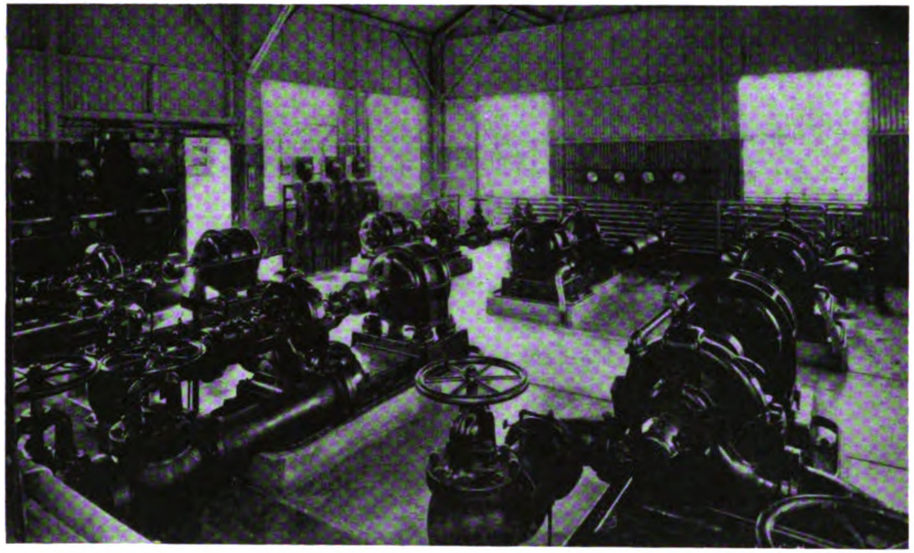


Fig. 12. Squirrel-cage Induction Motors Driving Circulating Pumps at a Natural Gasoline Plant

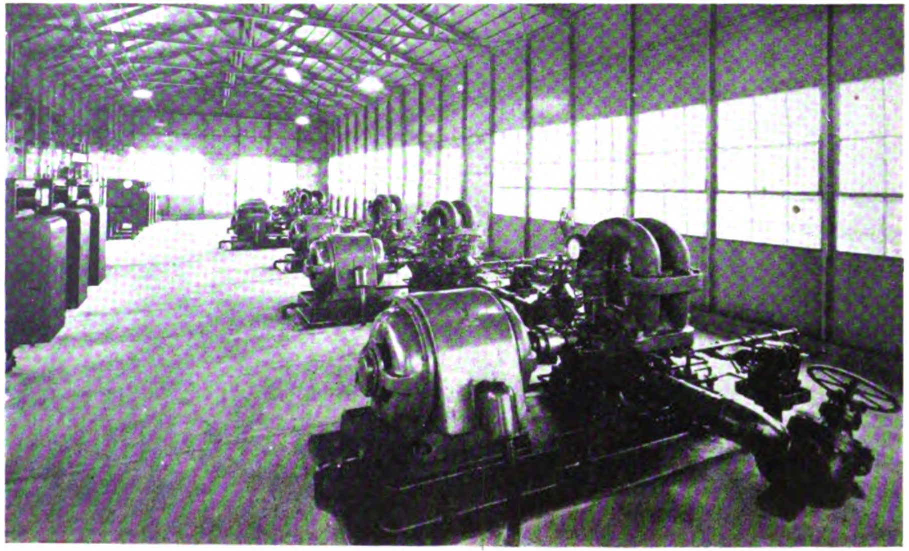


Fig. 13. Six 2-pole 250-hp. 3600-r.p.m. 2200-volt Ball-bearing Motors Driving Worthington Pumps for the Transportation of Oil Through Pipe Lines

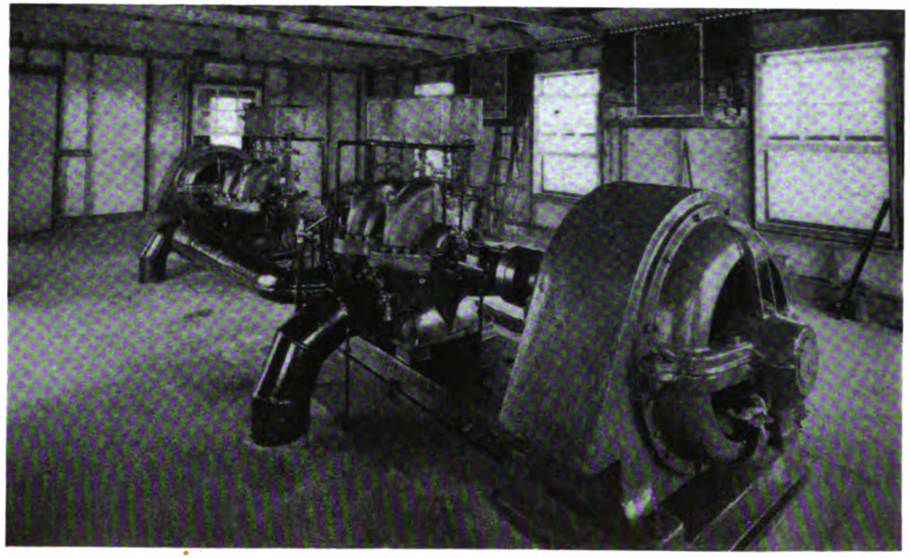


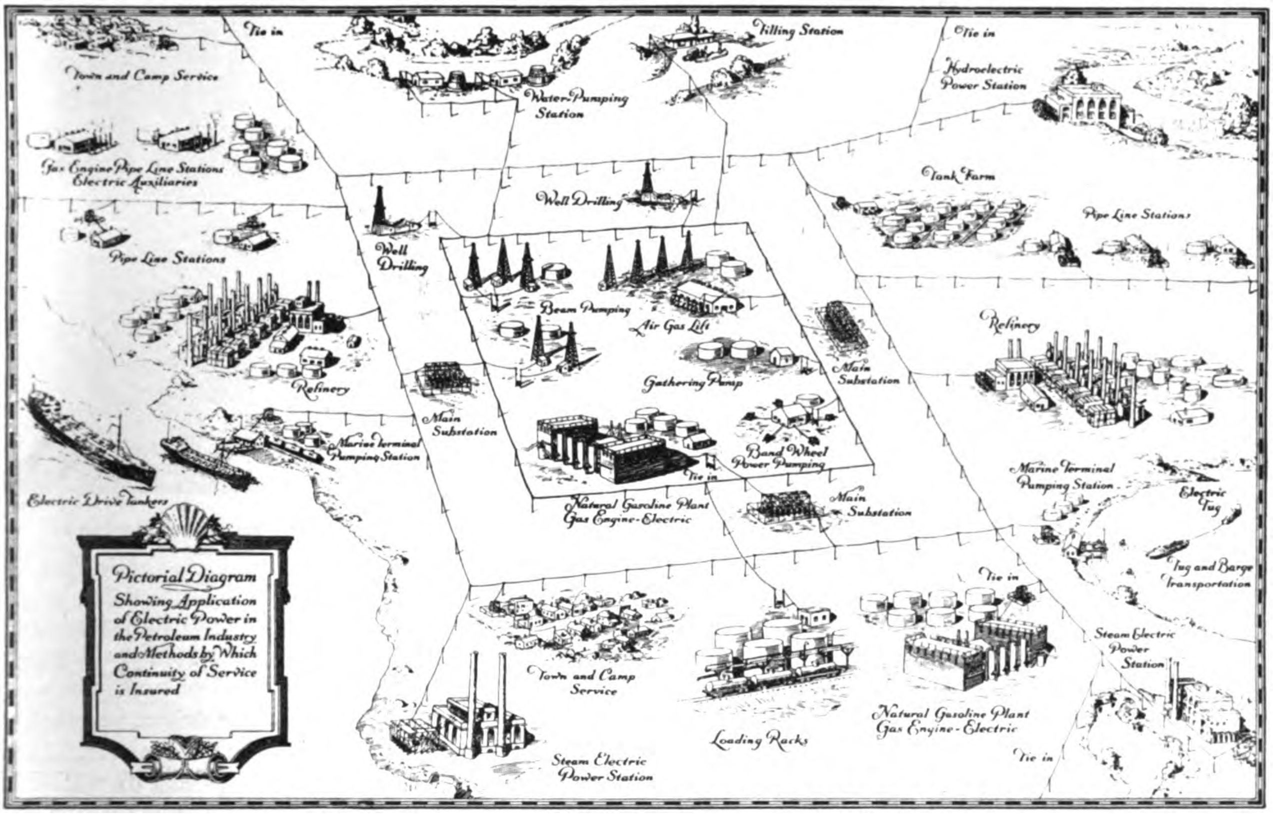
Fig. 14. Two 4-pole 400-hp. 1800 r.p.m. 440-volt Motors Driving Pumps for Transportation of Oil from Oklahoma Oil Fields

than it ever was before; and the reserves in the form of oil shales and of mined oil sand have not been touched. Just to give an idea of how great the petroleum industry is, let it be remembered that in about the time required to read this article, there will have been two and one-quarter miles of hole drilled; 114,000 barrels of crude brought to the surface; and two million gallons of gasoline burned in automobiles.

Into this vast field of industry electricity has steadily made its way. Already it is widely applied to the more usual operations of pumping and drilling, and in connection with the extensive use of compressors at various stages of production where the economy and utility of electrical equipment is conspicuously in evidence. Among the further uses to which electricity is being put are the various operations in natural gas production, the refining of petroleum, and in the transportation of products. The possibilities of electric heating in the oil industry are in the nascent state, so to speak, and hold promise of further contributions. Radio communication and arc welding equipment, also, have been employed to advantage.

Steam turbines for the production of electric power in the oil fields are, in addition, the means of controlling pressure in supplying process steam in its multifarious applications to the refining processes. In some instances, steam-driven pumps, installed as duplicates of motor-driven pumps, are operated at suitable intervals for the maintenance of heat balance.

Gas-engine-driven generators furnish a share of the electrical power. For this purpose units have been installed which utilize generators of as large as 2000-kw. capacity. Besides the facilities for producing electricity in isolated stations, the possibility of interconnection with larger power systems provides assurance of continuous power supply. Thus electricity is at all times made available, and thus it may contribute its part in adding to the overall convenience and reliability and economy of production.


Pictorial Diagram
Showing Application of Electric Power in the Petroleum Industry and Methods by Which Continuity of Service is Insured

Tie in
Town and Camp Service
Water-Pumping Station
Filling Station
Tie in
Hydroelectric Power Station
Gas Engine Pipe Line Stations Electric Auxiliaries
Well Drilling
Tank Farm
Pipe Line Stations
Well Drilling
Pipe Line Stations
Beam Pumping
Air Gas Lift
Refinery
Gathering Pump
Main Substation
Refinery
Main Substation
Marine Terminal Pumping Station
Band Wheel Power Pumping
Tie in
Electric Drive Tankers
Natural Gasoline Plant Gas Engine-Electric
Main Substation
Marine Terminal Pumping Station
Electric Tug
Tie in
Tug and Barge Transportation
Town and Camp Service
Steam Electric Power Station
Natural Gasoline Plant Gas Engine-Electric
Loading Racks
Steam Electric Power Station
Tie in

Marine Standards of Operating Efficiency

By **FRANK V. SMITH**

Federal and Marine Department, General Electric Company

THE idea of setting up a standard of operating efficiency is something quite new to the marine industry. Ships used to be built to have about "so much speed" when about "so much coal" was burned, and the horsepower depended upon the man power on the shovels. If in the past one wanted to be really scientific in such matters, he could divide the observed miles traveled by the tons of fuel burned and end up with a "highfalutin" term—knots per ton of coal. It was an all-inclusive term; and what it lacked in depth it made up for in breadth. If the ship headed into a storm the knots per ton might be zero; the best showing in knots per ton, of course, being made with favorable currents and winds. A segregation of the factors which contributed to the sum total of efficiency on such a scale could not be made; and the engineer who prided himself on the operation of an efficient plant many times had to suffer the poorest record.

The idea of selecting a gauge or value which would place the engineering plant on its own responsibility is of later invention. These newer standards charged the fuel used directly against the power delivered by the main propelling machinery. The fuel used by the auxiliary apparatus was included with that of the main propelling machinery; and no attempt was made at segregation. The total weight of fuel burned per hour was simply divided by the horsepower developed for propulsion, and the term "pounds of fuel per horsepower-hour for all purposes" evolved.

Now the method of ascertaining the horsepower developed by ships' propelling machinery differs in a wide degree. On a reciprocating engined ship, indicator cards are taken and the indicated horsepower calculated. The fuel value on such ships is therefore stated in terms of "pounds of fuel per indicated horsepower-hour for all purposes." The power readings may be taken once a year, once a month or even once a trip.

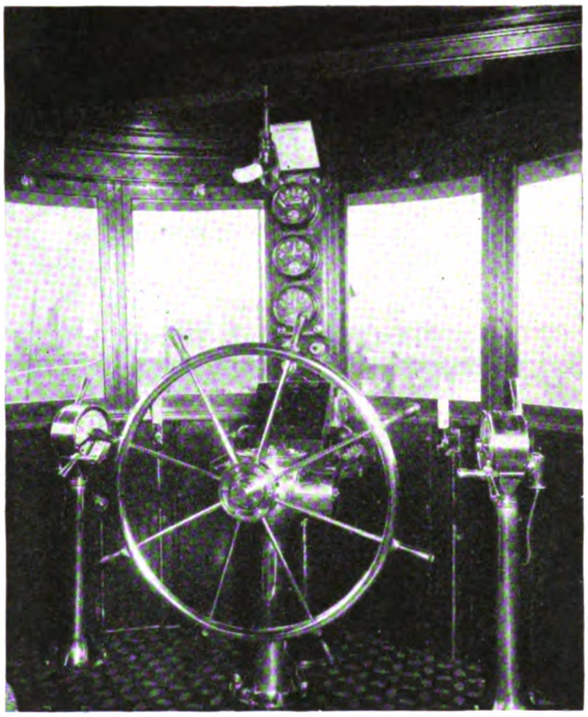


Fig. 1. Pilot House of an Electric Tugboat, Showing Instrument Panel to Furnish Indications of Power and Propeller Revolutions

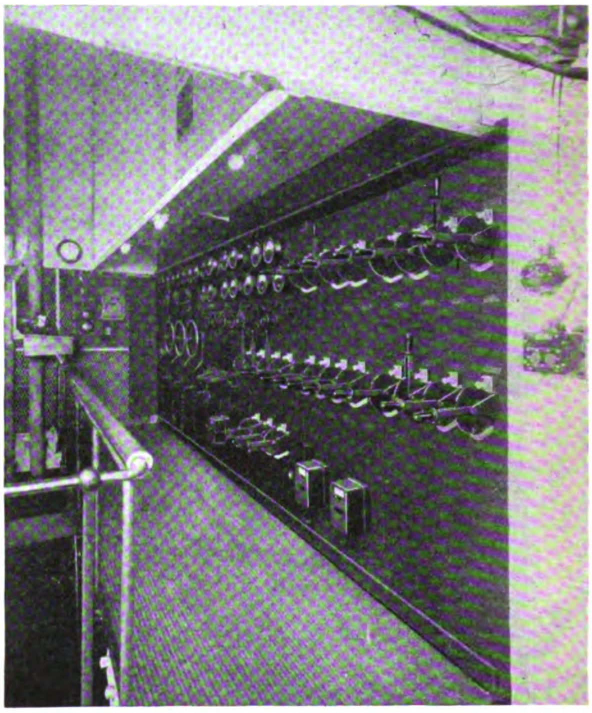


Fig. 2. Distribution Panel and Main Control Board on an Electrically-driven Tanker

Direct turbine and turbine gear driven vessels have their power calculated in a different manner. If the propelling equipments were subjected to water-rate tests, the test values can be used as the basis of a set of curves in which the shaft horsepower can be interpreted from the bowl pressure, vacuum, number of nozzles open, and the propeller revolutions.

A second method of determining the shaft horsepower is by means of a torsion meter. Both methods of ascertaining the power are probably accurate within plus or minus five per cent, with an additional correction for the human factor.

The use of the standard "pounds of fuel per indicated horsepower-hour" by reciprocating engined ships, and the "pounds of fuel per shaft horsepower-hour" by direct turbine and turbine gear driven ships, has caused quite a little confusion in the past, because the two values of power do not mean the same thing in a comparative sense. Quite a number of old-time engineers felt that their indicated horsepower was just as much as a shaft horsepower, although the mechanical efficiencies of their engines might be only 90 per cent.

The value "pounds of fuel per shaft horsepower-hour for all purposes" which is now becoming standardized as a measure of overall operating efficiency of a ship's power plant is, of course, an all-inclusive term and, therefore, cannot be used as a measure of the comparative economies of two different vessels, unless the ships' plants under consideration can be reduced to a common denominator for correct evaluation. The power distribution on vessels differs. A passenger vessel has many auxiliary power needs not common to a freight vessel, and vice versa.

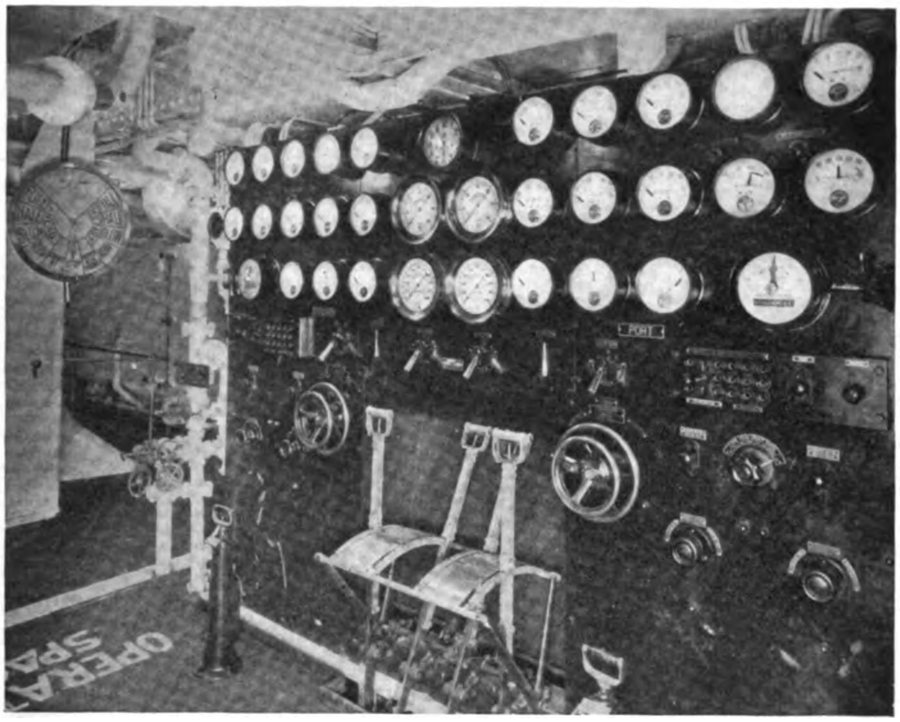


Fig. 3. Operating and Instrument Panel on a Large All-electric Passenger Liner

On the all-steam vessel in which the actual power developed by the main propelling machinery is but roughly approximated on an intermittent basis and where the extent of the steam auxiliary load is unknown and the actual total steam consumption is problematical, it is obvious that there can be no check on the efficiency of operation. A poor overall efficiency might be attributed to either poor fuel, poor combustion, or to low efficiency of the engines, but never with certainty for there is no means of check. Even under the tremendous disadvantage of having to work in the dark, so to speak, the marine engineer has taken his CO_2 readings, regulated and made fine adjustments in the apparatus under his charge, all in the hope that he might hit a little closer to some arbitrary value set up for him to shoot at as a mark of perfection.

The entrance of electric drive into the field of ship propulsion will have a wonderfully clarifying effect, and give a term such as "pounds of fuel per shaft horsepower" a reliable meaning.

The fact that the power output of the generating equipments can be constantly checked and visualized gives the engineer the feel of a pulse which at all times permits him to diagnose the operation of his plant. He can measure the power that is being used to drive the propellers and that which is used for the auxiliary needs of the vessel. He can translate power into terms of fuel for each individual purpose.

Of course, watching the flow of power by means of meters is possible only on an electric ship. The far-reaching effect that this newer engineering is going to have on the personnel of the ships is uplifting. With a larger knowledge and clearer understanding also comes a greater responsibility. Men could not be held resonsible for what they did not know. On the all-electric ship the maintenance of economies, within the limits of the design of the apparatus, becomes both a duty and a responsibility. Engineers accept this greater responsibility when means are put in their hands for the visualization of the inner workings of their plant.

Reflection of Transmission-line Surges at a Terminal Impedance

By **O. BRUNE**

Student at Massachusetts Institute of Technology, doing co-operative work in the Research Section of the Lightning Arrester Engineering Department of the General Electric Company, Pittsfield, Mass.

> *The method of analysis here outlined is strictly operational in character. The voltage surge is broken up into a few elements which are then expressed as simple operational functions, applied successively to the terminal impedance operators, and the resulting reflected voltage waves added directly, taking into account the proper time delay. This method is simple, and gives a good picture of the mechanism of reflecton.*
>
> —EDITOR

TRAVELING waves on a transmission line have always been a subject of absorbing interest, and in the past have received the attention of many of our leading engineers.

An absolutely correct and complete theoretical treatment of the subject leads into almost insuperable mathematical difficulties. For this reason most of the early work was confined to greatly simplified cases, such as the non-dissipative line and waves of rectangular wave-shape. Although much good work of this character was done, progress was bound to be slow. The lack of testing means for studying these phenomena in detail further hampered progress.

It is only within comparatively recent years that the methods of Oliver Heaviside have received the attention they deserve and from being the obscure intuition of a genius are rapidly becoming the everyday tool of the theoretical engineer. They find particularly ready application to the problem under consideration.

In addition, the cathode-ray oscillograph has provided a means of obtaining first-hand evidence as to the correctness of our theories and the closeness of our approximations.

It is due largely to the advent of these two new methods of study, in addition to the growing importance of the problem, that the study of traveling-wave phenomena is being pursued with added zest, and tremendous progress in this field may be expected in the near future.

This article furnishes a brief indication of what may be expected from these methods in one particular phase of the subject; *viz.*, the action of a lumped impedance on a traveling wave. The application of the Heaviside method to this problem is not new. It has received the attention of various authors,(1) (2) (3) but it does not seem to have been as extensively used among engineers as its convenience merits. Furthermore, the erroneous idea that surges of rectangular wave-shape are the only ones amenable to mathematical treatment should be dispelled.

The calculations for certain cases of reflection of non-rectangular surges on a transmission line at a terminal impedance are presented in this article. Oscillograms obtained on an actual transmission line under conditions similar to those assumed in the calculations are also shown, and the agreement is found to be very close.

In making the calculations certain assumptions regarding attenuation on the line have had to be made; and in as far as these assumptions lead to results that are checked by the oscillograms this may also be regarded as a contribution to the study of attenuation.

Problem to be Considered

In this article only the simple case of a lumped impedance *W* at the end of a transmission line, Fig. 1, will be considered. The extension to other cases will be evident.

This lumped impedance may represent the combined station impedance at the end of a line, when the wave-fronts are long compared with the distances between the various pieces of apparatus. It may also be made to include transmission lines leaving the station by putting the surge impedances of these lines into the lumped network.(2) In this case the lines leaving the station must be long enough so that reflections from their ends will not enter into the required solution. The surges traveling out on these lines will be given by the voltages appearing across the corresponding surge impedance in the network.

The question as to what specific impedances should be employed to represent various pieces of station apparatus at the end of a line (since these often contain distributed as well as lumped constants) need not be considered at present.

Considerable light will probably be thrown on this problem when cathode-ray oscillograms can be compared with calculations made on certain simplifying assumptions.

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(1) J. R. Carson: *Electric Circuit Theory*, Chap. IX.

(2) E. W. Boehne and L. H. Nothdurft: Master's Thesis, Massachusetts Institute of Technology, 1928. (Soon to be published.)

(3) V. Bush: *Operational Circuit Analysis*, Chap. XIV.

Outline of Methods of Calculation

The formulas for the reflection of a surge at a terminal resistance are well known. They are:

$$e_r = \frac{R-Z}{R+Z}\, e_v \qquad (1)$$

$$e_R = e_r + e_v$$

$$= \frac{2\,R}{R+Z}\, e_v \qquad (2)$$

where e_v is the voltage of the arriving surge; e_r is the voltage of the reflected surge; e_R is the resultant voltage across the resistance at the end of the line; R is the terminal resistance; and Z is the surge impedance of line.

If the terminal resistance R be replaced by an impedance W whose impedance operator may be written as $W(p)$, and the corresponding substitutions be made in the foregoing equations the operational equations for the voltages on reflection at the terminal impedance W will be obtained. For completeness, the further generalization of writing $Z(p) = \sqrt{\frac{lp+r}{cp+g}}$ instead of Z may be made. The complete operational expressions for the voltages on reflection are then:

$$e_r = \frac{W(p)-Z(p)}{W(p)+(Zp)}\, e_v \qquad (3)$$

$$e_W = \frac{2\,W(p)}{W(p)+Z(p)}\, e_v \qquad (4)$$

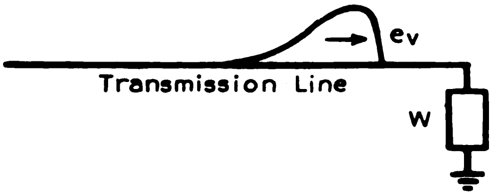

Fig. 1. Representation of a Transmission Line on which a Surge Wave is Traveling Toward a Lumped Impedance at the End of the Line

This method of arriving at operational solutions is well known. Anyone who wishes to convince himself of its applicability to this particular case may easily do so by writing down the conditions to be satisfied at the end of the line (*i.e.*, Kirchhoff's Laws) in terms of the operators concerned.

The operators in Equations (3) and (4) are general and give the solution for any wave-shape of the surge voltage e_v if this is substituted in the formulas.

There are, however, various methods of carrying through the solution for an arbitrary wave-shape. The following three may be mentioned: (1) the method employing the "extension formula" of Carson(4) which expresses the solution for an arbitrary wave in terms of the solution for a rectangular wave; (2) the method of breaking up the wave into a finite number of rectangular components, approaching sufficiently close to the original wave; (3) the method of breaking up the arbitrary wave into non-rectangular components, each of which can be expressed in a convenient operational form.

It is the last of these which has been found to be of considerable value and by means of which the calculated results in this article have been obtained. There are certain simple wave-shapes which lend themselves very readily to operational treatment. A short table of these is given in Appendix II. A sufficiently close approximation to a desired wave-shape can usually be obtained by compounding only two or three of such components. Further details of calculations with these wave-shapes will be found in Appendix III.

Arrangement by which Oscillograms of Reflected Surges on a Transmission Line Were Obtained

The oscillograms shown in this article were obtained in an extensive series of tests(5) which is being carried on by the Research Section of the Lightning Arrester Engineering Department of the General Electric Company, Pittsfield (Mass.).

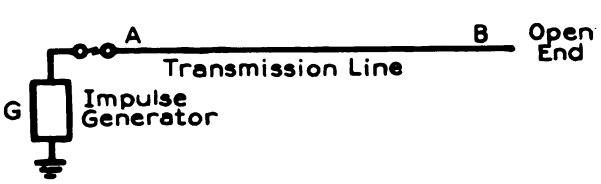

Fig. 2. Diagram of a Section of a Transmission Line with One End Open and an Impulse Generator, which Also Acts as a Lumped Impedance, Connected to the Other End Through a Spark Gap

A surge from a portable impulse generator was put on a certain length of transmission line, Fig. 2. This surge traveled out on the line and was reflected at the farther end. The reflected surge traveled back to the impulse generator, which acted like a lumped impedance at the end of the line, the gap at A being still ionized. If the cathode-ray oscillograph is placed at A, oscillograms of voltage of the original surge sent out by the surge generator G and of the voltage produced across G when the returning wave strikes it are obtained. The second voltage occurs after the first wave has traveled twice the length of the line. If the oscillograph is placed at B, it records the voltage of the original surge from G, and the voltage of the reflected surge from G (both at double value because of reflection at the open end at B). If we neglect all attenuation and distortion on the line, the first surge measured in both cases is that which on reflection at G gives the second surge. Very often, however, the change in wave-shape as the surge travels along the line is not negligible. This was verified by comparing oscillograms taken at A with oscillograms taken at B. It is also seen by comparing the calculated waves at A, shown in Figs. 4(c) and 5(c), with the corresponding waves measured at B, Figs. 4(b) and 5(b). The cause of the distortion is evidently corona loss, since all the distortion seems to occur above corona voltage. Without entering any further into the cause of this distortion, however, it is clear that it exists and should be taken into account in the calculations, if any accuracy is to be attained.

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(4) J. R. Carson: *Electric Circuit Theory*, Chap. II.

(5) The circuits used, together with further details of these tests, were described in the paper, "Cathode Ray Oscillograph Study of Artificial Lightning Surges on the Turners Falls Transmission Line," presented by K. B. McEachron and V. E. Goodwin at the Cincinnati Convention of the A.I.E.E., March, 1929.

The manner in which the reflection of the distorted wave is calculated gives an excellent illustration of how a given wave-shape can be approximated by compounding simpler wave-shapes.

Wave-shapes Given by the Impulse Generator

The impulse generator used, when discharging into the line, acts to all intents and purposes like a capacitance. The spark-gaps which connect the various condenser units in series will have some resistance and in the calculations this will be represented by an equivalent resistance in the circuit. This representation is not exact since the volt-ampere relation of a spark-gap is far from linear. The value which gives the best correspondence with measured values will be chosen.

When the line is connected to the impulse generator, a surge immediately travels out along the line, and the current in this surge is equal to the voltage divided by the surge impedance of the line. With respect to the impulse generator, therefore, the line acts like a resistance to ground. The only difference is that the energy of the current taken by the line is not dissipated in heat, but is contained in the resulting traveling wave. The resistance representation of the line ceases when the traveling wave reflected from the end of the line arrives back at the impulse generator. Equations (3) and (4), for reflections, apply to this case.

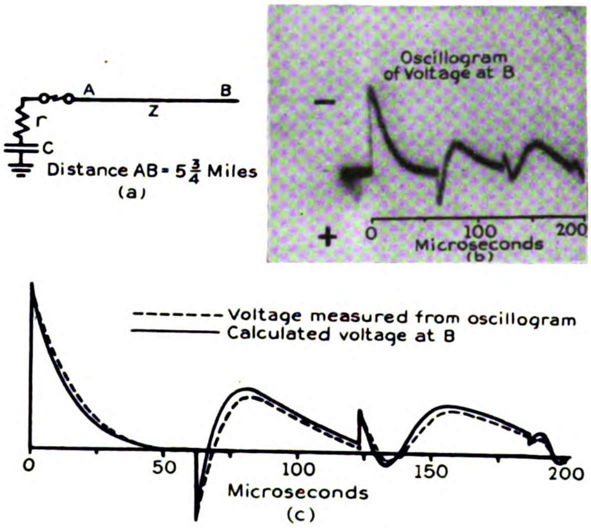

Fig. 3. Calculated and Test Values of a Low-voltage Surge on a Transmission Line When no Inductance Was Used in Series with the Impulse Generator

Two types of waves were put on the line by the impulse generator. First, the impulse generator was connected directly to the line as in Figs. 3(a) and 4(a). This corresponds to the case of the discharge of a capacity through a resistance. The wave-shape of the surge has therefore a vertical front and an exponentially decreasing tail as shown by the left- and right-hand sides of the curve in Fig. 4(c). Its form is given by the equation

$$e_v = E \cdot \frac{Z}{Z+r}\,\epsilon^{-t/C\,(Z+r)} \qquad (5)$$

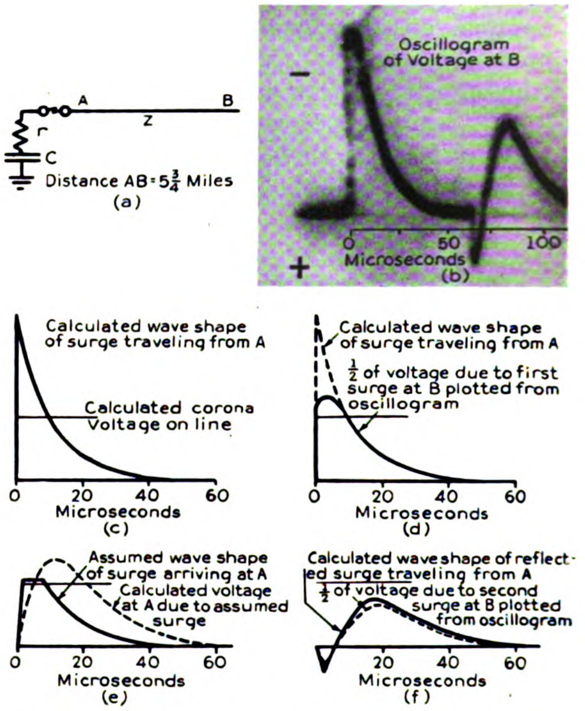

Fig. 4. Calculated and Test Values of a High-voltage Surge on a Line When no Inductance Was Used in Series with the Impulse Generator

For the other type of surge the line was connected to the impulse generator through an inductance coil, as in Fig 5(a). The condenser therefore discharged through an inductance and resistance in series. The wave-shape in Fig. 5(c) is given by

$$e_v = E \cdot \frac{Z}{S}\left(\epsilon^{-\left(\frac{R-S}{2L}\right)t} - \epsilon^{-\left(\frac{R+S}{2L}\right)t}\right) \qquad (6a)$$

$$\text{or } E\,\frac{Z}{L}\,t\,\epsilon^{-\frac{R}{2L}t} \qquad (6b)$$

$$\text{or } E\,\frac{2Z}{S'}\,\epsilon^{-\frac{R}{2L}t}\sin\frac{S't}{2L} \qquad (6c)$$

according as $R^2 \gtreqless \frac{4L}{C}$ and where $R = Z + r$

$$S = \sqrt{R^2 - \frac{4L}{C}} \text{ and } S' = \sqrt{\frac{4L}{C} - R^2}$$

Wave-shapes calculated from these formulas agree closely with surge voltages measured on the line at A.

This agreement, together with a knowledge of the surge impedance of the line, serves as a guide to finding the best value of resistance to represent the spark-gaps in the impulse generator.

These wave-shapes are all among those expressed in simple operational form in Appendix II and if they proceed along the line without distortion their reflections are immediately calculable without any compounding of waves. Fig. 3(b) shows an oscillogram obtained with a surge of low voltage where distortion was practically absent. Fig. 3(c) shows the corresponding calculated waves. The closeness with which these check the oscillogram is very satisfactory, considering the assumptions made. Details of the calculation will be found in Appendix III (A).

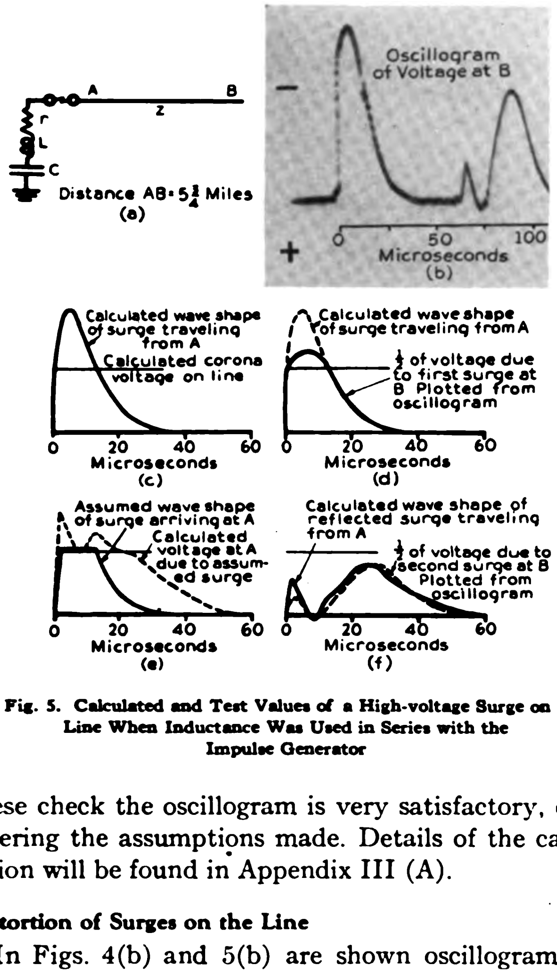

Fig. 5. Calculated and Test Values of a High-voltage Surge on a Line When Inductance Was Used in Series with the Impulse Generator

Distortion of Surges on the Line

In Figs. 4(b) and 5(b) are shown oscillograms of high-voltage surges measured at the point *B* on the line, Fig. 2, together with the reflected waves produced when these surges proceed back over the line and strike the impulse generator. In Fig. 4 the impulse generator was directly connected to the line, while in Fig. 5 it was connected to the line through an inductance coil.

Careful measurement shows a marked difference in the front of these waves. (The oscillograms are somewhat deceptive as the axes of voltage and time are not exactly at right angles.) In Figs. 4(c) and 5(c) are shown the calculated voltages at *A* for the two cases. In Figs. 4(d) and 5(d) the measured voltages at *B* (divided by two to allow for reflection at the open end) are plotted to the same scale as the calculated voltage at *A*, the latter being shown dotted. The difference in voltage at the two ends is apparent and agrees also with sphere-gap measurements made in the two cases.

The loss of voltage on the crest of the wave is evidently due to corona. Although starting out with different values of voltage, the two waves have been reduced to practically the same maximum voltage at the end of the line. At voltages below corona voltage, the agreement between the calculated and the measured waves is still very close. On reflection at the open end, a further loss will occur for the short distance where the incoming and reflected voltages superimpose to produce voltages above the critical corona voltage.

For this reason we should also expect a marked attenuation on the front of the reflected wave proceeding from the open end, for while the front of the original surge was not attenuated as long as it remained below corona voltage(6) the front of the outgoing surge will be entirely above corona voltage for a short length of time.

All these considerations have led to the assumption of the wave-shapes shown in Figs. 4(e) and 5(e) for the waves which reach the impulse generator after the original surge has traveled twice over the line.

Method of Calculating Reflection of Distorted Waves

To make the calculations as simple as possible these waves have been assumed to have a uniformly sloping front, flat top, and an exponential tail. The fronts have been taken with the same slope in both cases and the tops of the same height. The tails of the waves have been made to agree with the tails of the measured surge voltages at *B*. Although this representation will not be quite exact it will be sufficiently close for our purposes.

Waves of this type are readily obtained by compounding waves of simple wave-shape as shown in Fig. 6. To begin with, a wave of uniform slope (wave *a* in Fig. 6) is taken. After a time corresponding to the length of the front of the required wave, another wave of negative slope (wave *b* in Fig. 6) equal but opposite to the slope of the first wave is superimposed. The addition of these two waves gives the flat top desired. The tail is now readily obtained by superimposing a third wave which is negative and of exponential form (wave *c* in Fig. 6). The reflection will now be the sum of the reflections due to the separate components. Further details of the calculations are given in Appendix III.

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(6) Skin effect is often mentioned as a factor in attenuation of wave-front. Calculations show however that on copper conductors, over the distances used in these tests, the effect is small except on exceptionally steep wave-fronts. The "perpendicular" wave-front measured on the oscillograms is of course only approximately so, *i.e.*, its duration is very short compared to the other times entering into the calculations.

In connection with this see also:

F. Moeller: "Die Abflachung steiler Wellenstirnen unter Berucksichtigung der Stromverdrangung im Leiter." *Archiv. fur Elektrot.*, B. XV., 1926.

H. Pleijel: "Traveling Waves and Their Alteration of Form During Their Propagation Along Aerial Conductors." Lecture before Electrotechnical Section of the Swedish Technological Ass'n.

The reflections from the impulse generator, calculated on these assumptions are shown in Figs. 4(f) and 5(f) and comparison with the measured reflection shows an agreement which is as close as can be expected considering all the uncertainties involved. Moreover, on plotting the calculated voltages across the impulse generator, shown dotted in Figs 4(e) and 5(e) and given by the sum of the incoming and reflected surges, Equation (4), it will be seen that the voltage at the impulse generator again exceeds corona voltage on certain portions of the wave, and these correspond with those for which the variation between the calculated and measured waves is most marked. On the whole, therefore, the agreement between measured and calculated values is very satisfactory.

The oscillogram in Fig. 7 is shown as a case of voltage measured at A when the impulse generator was connected as in Fig. 5(a). Since the constants in this case are different from those in Fig. 5, values from Fig. 7 are not plotted in Fig. 5 but the similarity between the shape of wave measured in Fig. 7 and the shape of wave calculated in Fig. 5(e) is evident.

Conclusions

It is thought that the methods here outlined will be of considerable value as an aid in understanding what happens to a transmission-line surge when it strikes station apparatus. Before anything definite can be done in this direction, however, it is necessary to know more about the kind of surges to be expected and the type of impedance to be assumed for station apparatus with respect to surges. Considerable information on these two points will probably be gained in the near future from field investigations on lightning and from systematic studies of surges on actual transmission lines.⁽⁵⁾

The particular calculations presented in this article were made with an entirely different object in view, *viz.*, the explanation of observed phenomena in a certain series of tests. They have indirectly added considerably to our experimental knowledge of the action of corona and have aided in planning additional tests to verify suspected phenomena. Their success in this case may be some indication of their possibilities in the wider field, *i.e.*, the effect of station apparatus on transmission line surges.

Incidentally, also, calculations of this type will always have to be considered in making measurements of surge voltages to see what effect the measuring apparatus has on the surges to be measured. This effect may be small enough to be neglected or it may have to be taken into account. In either case its magnitude should be calculated.

APPENDIX I

Notation

e_r = Voltage of surge arriving at the terminal impedance (as function of time)

e_r = Voltage of reflected surge traveling from terminal impedance

e_w = Voltage across terminal impedance due to arriving surge ($= e_v + e_r$)

$W(p)$ = Impedance operator of lumped impedance at the end of the line

(Zp) = Impedance operator of the line $= \sqrt{\dfrac{lp+r}{cp+g}}$

Z = Surge impedance of the line when resistance and leakance are neglected $= \sqrt{\dfrac{l}{c}}$

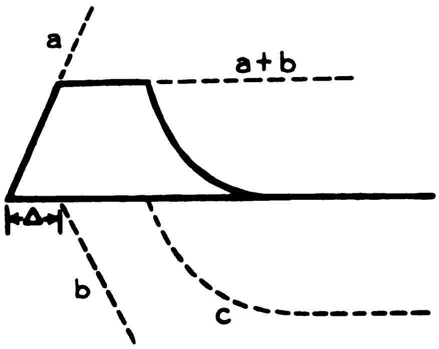

Fig. 6. Representation of the Synthetic Method Employed in the Calculations for Compounding an Actual Wave Form from Three Simple Components

In the following, only the case where $Z(p) = Z = \sqrt{\dfrac{l}{c}}$ will be considered. These equations then hold:

$$e_r = \frac{W(p) - Z}{W(p) + Z} e_v$$

$$= \left(1 - \frac{2Z}{W(p)+Z}\right) e_v$$

$$= e_v - \rho \tag{7}$$

where
$$\rho = \frac{2Z}{W(p)+Z} e_v \tag{8}$$

further
$$e_w = e_v + e_r$$

$$= 2e_v - \rho \tag{9}$$

Knowing e_v, Z, and $W(p)$ it therefore only remains to evaluate ρ and all voltages on reflection will be known.

The Heaviside notation $\boldsymbol{1}$ for a rectangular wave will be used throughout. This usually denotes a certain function of time and to bring this out more forcibly it will sometimes be written $\boldsymbol{1}(t)$. Consistently with this, when a rectangular wave begins at time Δ instead of time zero, this may be written as $\boldsymbol{1}(t - \Delta)$. The notation used is thus

$\boldsymbol{1}(t)$ = A rectangular wave of unit height and infinite length, beginning at time 0.

$\boldsymbol{1}(t-\Delta)$ = A rectangular wave of unit height and infinite length beginning at time Δ.

APPENDIX II

The simple cases of time functions readily expressible in operational form are given in Table I for reference in the calculations to be carried out later. They may be considered as simple wave-shapes which may approximate a surge voltage in a given case, or which may be compounded to produce less simple wave-shapes. The correspondence between the time function and the operator will be found proved in any text book on the elements of operational calculus.(7)

APPENDIX III

Evaluation of e_r and e_w in Particular Cases

The following solutions of particular cases are worked out in order to illustrate the method of procedure and to lead up to the cases for which oscillograms are shown. No attempt to consider general cases beyond those immediately applicable to the experimental cases has been made.

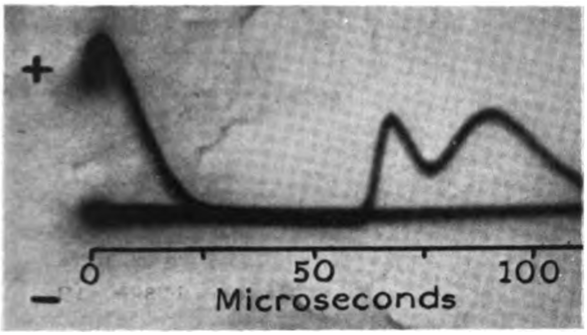

Fig. 7. Oscillogram of Voltage at the Impulse Generator with the Same Circuit Connections as in Fig. 5 but with Different Circuit Constants

(A). *The Terminal Impedance as a Capacity with Series Resistance (Figs. 3 and 4)*

$$W(p)=r+\frac{1}{Cp};\quad \rho=\frac{2Z}{Z+r+\dfrac{1}{Cp}}\,e_v$$

$$=\frac{2Z}{Z+r}\,\frac{p}{p+\lambda}\,e_v \tag{10}$$

$$\text{where}\qquad \lambda=\frac{1}{C(Z+r)} \tag{11}$$

(*a*). Let
$$e_v=\epsilon^{-\mu t}\,\mathbf{1}=\frac{p}{p+\mu}\,\mathbf{1} \tag{12}$$

This applies for the case shown in Fig. 3.

The particular condition which existed in this case is $\mu=\lambda$. Solving for this case only,

$$\rho=\frac{2Z}{Z+r}\,\frac{p^2}{(p+\lambda)^2}\,\mathbf{1}$$

$$=\frac{2Z}{Z+r}\,(1-\lambda t)\,\epsilon^{-\lambda t}\,\mathbf{1} \tag{13}$$

$$e_r=\left(\frac{2Z}{Z+r}\lambda t-\frac{Z-r}{Z+r}\right)\epsilon^{-\lambda t}\,\mathbf{1} \tag{14}$$

$$e_w=\left(\frac{2Z}{Z+r}\lambda t-\frac{2r}{Z+r}\right)\epsilon^{-\lambda t}\,\mathbf{1} \tag{15}$$

(*a′*). The second reflection (Fig. 3) is readily obtained.

If e_r proceeds out on the line and is reflected back from an open end,

$$e_v'=e_r=\left(\frac{2Z}{Z+r}\,\frac{\lambda p}{(p+\lambda)^2}-\frac{Z-r}{Z+r}\,\frac{p}{p+\lambda}\right)\mathbf{1}$$

$$=\frac{\lambda p-up^2}{(p+\lambda)^2}\,\mathbf{1} \tag{16}$$

TABLE I

	Time Function	Operational Form
1 *a*	$\epsilon^{-\lambda t}\,\mathbf{1}$	$\dfrac{p}{p+\lambda}\,\mathbf{1}$
b	$(1-\epsilon^{-\lambda t})\,\mathbf{1}$	$\dfrac{\lambda}{p+\lambda}\,\mathbf{1}$
2 *a*	$\dfrac{\alpha}{\sigma}\left\{\epsilon^{-(\alpha-\sigma)t}-\epsilon^{-(\alpha+\sigma)t}\right\}\mathbf{1}$	$\dfrac{2\alpha p}{p^2+2\alpha p+\nu^2}\,\mathbf{1}$ where $\sigma^2=-\omega^2=\alpha^2-\nu^2$ and *b* applies when $\sigma=0$
b	$2\alpha t\,\epsilon^{-\alpha t}\,\mathbf{1}$	
c	$\dfrac{2\alpha}{\omega}\,\epsilon^{-\alpha t}\sin\omega t\,\mathbf{1}$	
3	$\kappa t\,\mathbf{1}$	$\dfrac{\kappa}{p}\mathbf{1}$

$$\text{where}\quad u=\frac{Z-r}{Z+r} \tag{17}$$

$$\rho'=(1+u)\,\frac{p\,(\lambda p=up^2)}{(p+\lambda)^3}\,\mathbf{1}$$

$$=(1+u)\left\{-u+(2u+1)\,\lambda t-\frac{u+1}{2}\,\lambda^2t^2\right\}\epsilon^{-\lambda t}\,\mathbf{1} \tag{18}$$

$$e_r'=\left\{u^2-2u\,(1+u)\,\lambda t+\tfrac{1}{2}\,(1+u)^2\,\lambda^2t^2\right\}\epsilon^{-\lambda t}\,\mathbf{1} \tag{19}$$

The curves in Fig. 3(c) are calculated from Equations (14) and (19) for $z=600$ ohms, $r=230$ ohms, and $C=1/64$ microfarad.

(*b*). Let
$$e_v=\kappa t\,\mathbf{1}=\frac{\kappa}{p}\,\mathbf{1} \tag{20}$$

This corresponds to either component *a* or *b* in Fig. 6 for obtaining the approximate waves assumed in Fig. 4(e).

$$\rho=\frac{2Z}{Z+r}\,\frac{p}{p+\lambda}\,\frac{\kappa}{p}\,\mathbf{1}$$

$$=\frac{2Z}{Z+r}\,\frac{\kappa}{\lambda}\,(1-\epsilon^{-\lambda t})\,\mathbf{1}$$

$$=2ZC\kappa\,(1-\epsilon^{-\lambda t})\,\mathbf{1} \tag{21}$$

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(7)See for example: "Heaviside's Operational Calculus as Applied to Engineering and Physics," by Dr. E. J. Berg, GENERAL ELECTRIC REVIEW, Dec., 1927, and March and April, 1928.

where substitution for λ is made from Equation (11)

$$e_r = \kappa\,(t - 2\,Z\,C\,[1-\epsilon^{-\lambda t}])\,\mathbf{1} \qquad (22)$$

$$e_w = \kappa\,(2\,t - 2\,Z\,C\,[1-\epsilon^{-\lambda t}])\,\mathbf{1} \qquad (23)$$

(This result is interesting in that it shows that the final effect of a condenser on this type of wave is to delay it by a time $2ZC$ and that this final effect is independent of the resistance in series with the line.)

(*b'*). Let $\quad e_v = \kappa t\,\mathbf{1}\,(t) - \kappa\,(t-\Delta)\,\mathbf{1}\,(t-\Delta) \qquad (24)$

This is the sum of components *a* and *b* in Fig. 6. The solution is obtained by superimposing two solutions as given by Equation (22) separated by a time Δ.

Then $\quad e_r = \kappa\,(t - 2ZC\,[1-\epsilon^{-\lambda t}])\,\mathbf{1} \qquad (25a)$

when $0 \overline{<} t \overline{<} \Delta$

and $\quad e_r = \kappa\,(\Delta - 2ZC\,[\epsilon^{\lambda\Delta}-1]\,\epsilon^{-\lambda t})\,\mathbf{1} \qquad (25b)$

when $\Delta \overline{>} t \overline{<} \infty$

Note that $k\Delta$ is the height of the original wave.

(*c*). Let $\quad e_v = (1-\epsilon^{-\lambda t})\,\mathbf{1} = \dfrac{\lambda}{p+\lambda}\,\mathbf{1} \qquad (26)$

This with negative sign is component *c* in Fig. 6.

$$\rho = \frac{2\,Z}{Z+r}\;\frac{p\lambda}{(p+\lambda)^2}\,\mathbf{1}$$

$$= \frac{2\,Z}{Z+r}\,\lambda t\;\epsilon^{-\lambda t}\,\mathbf{1} \qquad (27)$$

$$e_r = \left\{1 - \left(1 + \frac{2\,Z}{Z+r}\,\lambda t\right)\epsilon^{-\lambda t}\right\}\mathbf{1} \qquad (28)$$

$$e_w = \left\{2 - \left(2 + \frac{2\,Z}{Z+r}\,\lambda t\right)\epsilon^{-\lambda t}\right\}\mathbf{1} \qquad (29)$$

Using Equations (25a), (25b), (28), and (29), the curves in Fig. 4(e) and 4(f) have been calculated for the values $Z = 500$ ohms, $r = 140$ ohms, $C = 1/64$ microfarad, $\Delta = 2$ microseconds, and the beginning of the tail occurring when $t = 9$ microseconds

(*B*). *The Terminal Impedance at the End of the Line as a Series Combination of Capacity Resistance and Inductance, Fig. 5(a)*

$$W(p) = Lp + r + \frac{1}{Cp};\quad \rho = \frac{2\,Z}{Lp + (Z+r) + \dfrac{1}{Cp}}\,e_v$$

$$= \frac{2\,Z}{L}\;\frac{p}{p^2+2\alpha p+\nu^2}\,e_v \qquad (30)$$

where $\quad \alpha = \dfrac{Z+r}{L},\ \nu^2 = \dfrac{1}{LC} \qquad (31)$

(*a*.) Let $\quad e_v = \kappa t = \dfrac{\kappa}{p}\,\mathbf{1} \qquad (32)$

This is component *a* or *b* of the wave in Fig. 6 to be used for producing the approximate wave assumed in Fig 5(e).

$$\rho = \frac{2Z}{L}\cdot\frac{p}{p^2+2\alpha p+\nu^2}\cdot\frac{\kappa}{p}\,\mathbf{1}$$

$$= \frac{2Z}{L}\cdot\frac{\kappa}{\nu^2}\left(1 - \frac{p^2+2\alpha p}{p^2+2\alpha p+\nu^2}\right)\mathbf{1}$$

$$= 2ZC\,\kappa\left\{1 - \frac{\alpha+\sigma}{2\sigma}\,\epsilon^{-(\alpha-\sigma)t} + \frac{\alpha-\sigma}{2\sigma}\,\epsilon^{-(\alpha+\sigma)t}\right\}\mathbf{1} \qquad (33a)$$

$$\text{or } 2ZC\,\kappa\left\{1 - (1+\alpha t)\,\epsilon^{-\alpha t}\right\}\mathbf{1} \qquad (33b)$$

$$\text{or } 2ZC\,\kappa\left\{1 - \frac{\nu}{\omega}\,\epsilon^{-\alpha t}\sin(\omega t+\delta)\right\}\mathbf{1} \qquad (33c)$$

according as α_2 is $>$, $=$, or $< \nu^2$ and where $\sin\delta = \dfrac{\omega}{\nu}$

For the same conditions

$$e_r = \kappa\left[t - 2ZC\left\{1 - \frac{\alpha+\sigma}{2\sigma}\,\epsilon^{-(\alpha-\sigma)t} + \frac{\alpha+\sigma}{2\sigma}\,\epsilon^{-(\alpha+\sigma)}\right\}\right]\mathbf{1} \qquad (34a)$$

$$\text{or } \kappa\left[t - 2ZC\left\{1 - (1-\alpha t)\,\epsilon^{-\alpha t}\right\}\right]\mathbf{1} \qquad (34b)$$

$$\text{or } \kappa\left[t - 2ZC\left\{1 - \frac{\nu}{\omega}\,\epsilon^{-\alpha t}\sin(\omega t+\delta)\right\}\right]\mathbf{1} \qquad (34c)$$

(In this case, also, this type of wave is delayed by a time $2ZC$ in the final condition. The addition of inductance has made a difference only to the manner in which this final condition is reached but not to the final condition itself. Compare with Equations (22) and (23). Similar relations have been found for cases where the terminal impedance acts finally like a resistance or like a short circuit, the delay in this case being $\dfrac{2L}{Z}$, where L is the inductance in series with the resistance.)

(*b*). Let $\quad e_v = (1-\epsilon^{-\lambda t}) = \dfrac{\lambda}{p+\lambda}\,\mathbf{1} \qquad (35)$

This is component *c* of the wave in Fig. 6 to be used for producing the approximate wave assumed in Fig. 5(e).

$$\rho = \frac{2Z}{L}\cdot\frac{p}{p^2+2\alpha p+\nu^2}\cdot\frac{p}{p+\lambda}\,\mathbf{1}$$

$$= \frac{2Z}{L}\cdot\frac{\lambda}{\lambda^2-2\alpha\lambda+\nu^2}\left[\frac{p}{p+\lambda} - \frac{p^2+(2\alpha-\lambda)\,p}{p^2+2\alpha p+\nu^2}\right]\mathbf{1}$$

Writing $\gamma^2 = \lambda^2 - 2\alpha\lambda + \nu^2$

$$\rho = \frac{2Z}{L}\cdot\frac{\lambda}{\gamma^2}\left\{\epsilon^{-\lambda t} - \frac{\alpha+\sigma-\lambda}{2\sigma}\,\epsilon^{-(\alpha-\sigma)t} + \frac{\alpha-\sigma-\lambda}{2\sigma}\,\epsilon^{-(\alpha+\sigma)t}\right\}\mathbf{1} \qquad (36a)$$

$$\text{or } = \frac{2Z}{L}\cdot\frac{\lambda}{\gamma^2}\left\{\epsilon^{-\lambda t} - [1+(\alpha-\lambda)\,t]\,\epsilon^{-\alpha t}\right\}\mathbf{1} \qquad (36b)$$

$$\text{or } = \frac{2Z}{L}\cdot\frac{\lambda}{\gamma^2}\left\{\epsilon^{-\lambda t} + \frac{\gamma}{\omega}\,\epsilon^{-\alpha t}\sin(\omega t-\delta)\right\}\mathbf{1} \qquad (36c)$$

according as α^2 is $>$, $=$, or $< \nu^2$ and where $\sin\delta = \dfrac{\omega}{\gamma}$.

The corresponding values of e_r and e_w can immediately be written down; but there is no advantage gained as in these formulas, because of the magnitude of the quantities involved, it is often more convenient to calculate ρ separately and then find e_r from Equation (7).

Calculations for the case in Fig. 5 have been made on the following assumptions: $Z = 500$ ohms, $r = 140$ ohms, $L = 1600$ microhenrys, and $C = 1/64$ microfarad. This gives $\alpha^2 = \nu^2$ and hence Equations (34b) and (36b) are used.

For the sum of components a and b in Fig. 6, Equation (35b) must be added to a corresponding Equation with $(t - \Delta)$ substituted for t, and with the opposite sign. This reduces to

$$e_r' = \kappa\{\Delta - 2ZC\,\epsilon^{-\alpha t}[n\,(1+\alpha t) - q]\} \qquad (37)$$

where $n = \epsilon^{\alpha\Delta} - 1$, and $q = \alpha\Delta\,\epsilon^{\alpha\Delta}$.

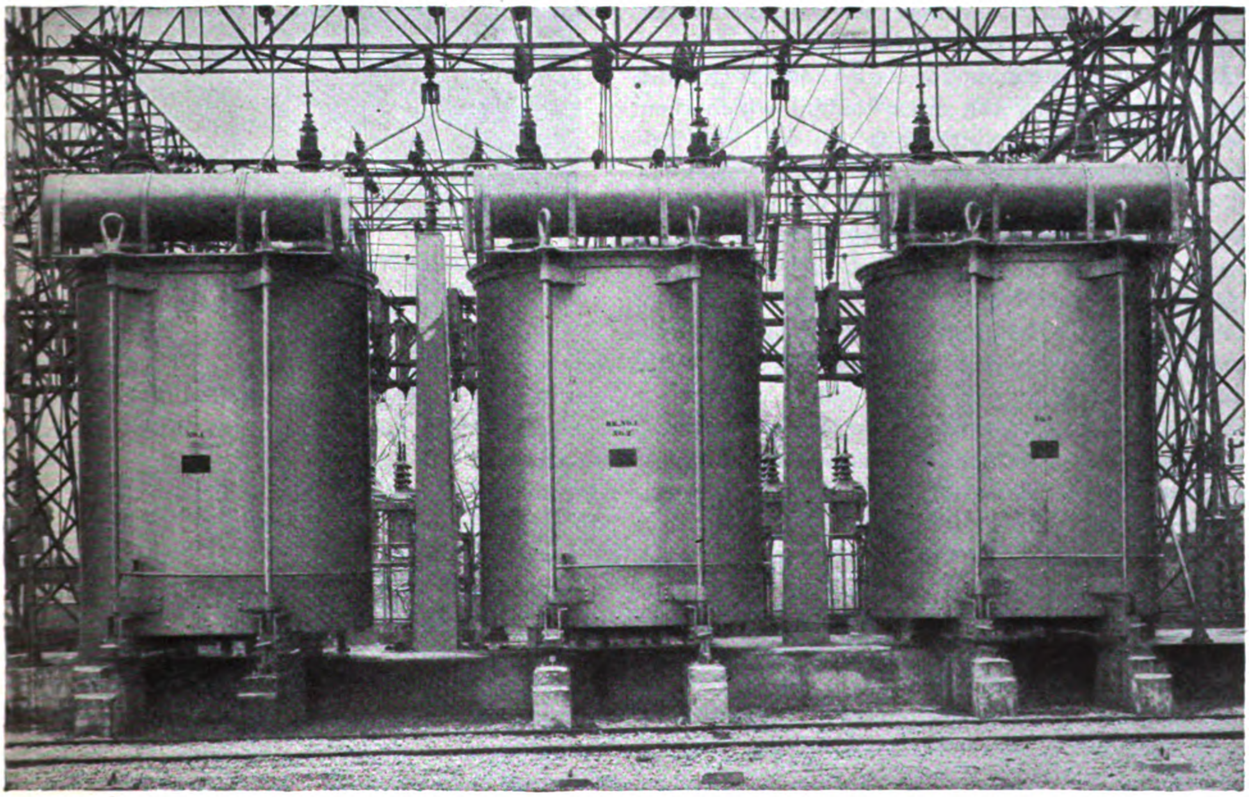
By using this equation instead of calculating the waves separately and then taking the difference, the work may be shortened somewhat.

The value chosen for Δ was 2 microseconds and for the beginning of the tail of the wave 12.5 microseconds.

Note

The values chosen for the various constants in the foregoing calculations were to a certain extent arbitrary, the choice being largely guided by the correspondence obtained with the oscillograms. The value for capacitance in the impulse generator was taken from the rating of the capacitors used. The value of inductance of the coil was calculated from its dimensions. The surge impedance of the line was based on calculated values but here again there may be considerable variation due to the change in effective ground level. There has thus been no hesitation in using different values in two sets of tests made on different days where this would agree better with the oscillograms. Furthermore, it is quite possible that the surge impedance varies with the voltage of the surge (corona and ground resistance effects). All these effects will be more fully investigated. The choice of gap resistance has been entirely arbitrary as there is nothing for guidance but agreement with measured values of voltage.

Oil Conservators with Service Record



During a period of nine years it has not been found necessary to filter or purify the oil in these 10,000-kv-a. 120-000-volt transformers of the Ohio Power Company at Canton (Ohio).

Reclaiming Gasoline Engine Oils

Treatment of Used Oil—Superior Lubricant—Power Companies Among Users of Refiners—Description of Process—Operation

By CHARLES VAN BRUNT

Research Laboratory, General Electric Company

EVERY automobile owner knows that proper care for his machine means that he must change the oil in the crank case every so often. Even the most modern devices incorporated in the power plant of the automobile, such as filters and crank case ventilators, do not obviate this necessity as both devices serve at best merely to lengthen the period during which one filling can safely be kept in service. Neither can cope with the organic acidity developed in the oil by oxidation, which may in time become sufficiently strong to attack metal parts when a little water is present. An increasing tendency to "sludge," a phenomenon uncomfortably familiar to transformer operators, with resultant rapid overloading of the filter is also to be expected. Furthermore, even with crank case ventilation, dilution by fuel with the accompanying diminution of "body," or viscosity, still occurs.

Ownership of large fleets of trucks or buses is already very large and is increasing rapidly, and railroads are installing gasoline, or gasoline-electric equipment for short-line service. These interests cannot and do not contemplate with indifference the waste represented by the discarded oil which their schedules of engine maintenance call for; and any means by which this oil can profitably be reclaimed and returned to service is regarded by them as an important investment, not only from the point of view of reduction in oil costs, but even more so in engine maintenance, because lower oil costs mean the possibility of more frequent change; and no one can question the effect of better lubrication on the life of the power plant.

Service stations, too, which in the course of business accumulate large quantities of crank case drainings, are seriously concerned with the matter of disposal. If this does not already constitute a problem, it presently will do so, as recent municipal surveys have brought out the need of action to combat the dangerous nuisance involved in the prevalent practice of dumping the drainings into sewers. Reclamation of these oils, especially if feasible by devices which service stations can own and operate as part of their regular equipment, would turn this nuisance into a source of profit.

Reclamation of crank case oils is not a new proposition. It has long been recognized as being entirely practicable on a regular refinery scale. The difficulty here has lain largely in the cost of collection of the drainings and in the variation in the character of the supply. Enterprises of this sort do not in general seem to have survived. Smaller-scale plants, drawing from known and limited sources, and using a process consisting essentially in an alkali treatment and steam distillation to remove diluents have been successfully operated for many years, for example, by the air service during the war; and, although not practicable for general use, these have served to demonstrate beyond a doubt the fact that oil so reclaimed is, if anything, superior to the original for its intended purpose. It is a better lubricant, and gives superior results both in quality and in quantity of carbon deposits. This point is now conceded by practically all who have made an impartial study of the subject.

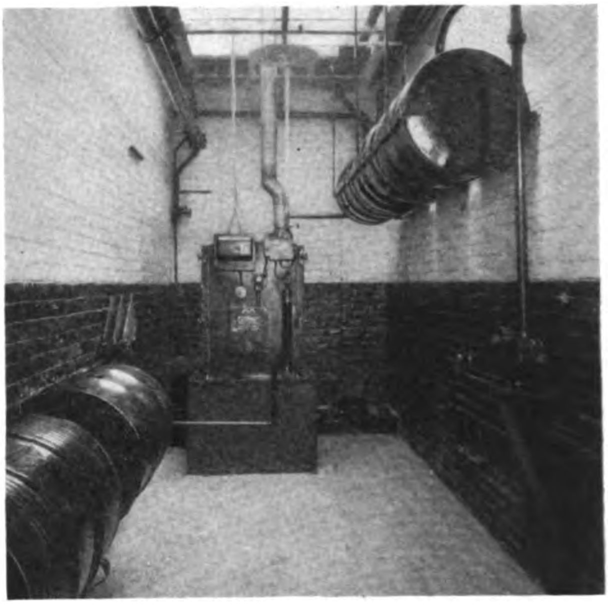


Fig. 1. An Installation of a Refinoroil of 20 Gal. Per Day Capacity in the Garage of a Public Utility, Where it is Used for the Reclamation of Oil from a Fleet of 80 Buses

From what has been said the conclusion is fairly obvious that there is a large and growing field for reclamation apparatus in small units which can be successfully operated by the personnel already employed. The fact that reclaimed oil possesses such remarkable qualities as a lubricant has led to the installation of refining machines in considerable numbers in this country by electric power and railway utilities and companies operating buses and taxis, and similar enterprises, and at flying fields and airports. Substantial savings have already been reported. The Research Laboratory at Schenectady took up the study of this proposition some years ago, and the result is a machine now being manufactured and marketed by a licensee.*

The process used in this machine embodies the fundamental alkali treatment and removal of diluents by heat. Its unique features lie in the use of concentrated silicate of soda ("water glass") as alkali, and in evaporating rather than distilling off the diluents by running the oil in a thin film over corrugated electrically-heated plates in a strong draft. Concentrated silicate of soda was found to have the property both of correcting acidity, and removing all solid matter and certain other deleterious products of oxidation, forming therewith a dense and heavy sludge which not only settles almost immediately but also has the unique and useful property of sinking completely out of the oil into an underlying body of water. This is maintained in constant flow, thus continuously flushing the sludge, which is oil-free, into the drain. These properties make possible an automatic, continuous process from beginning to end.

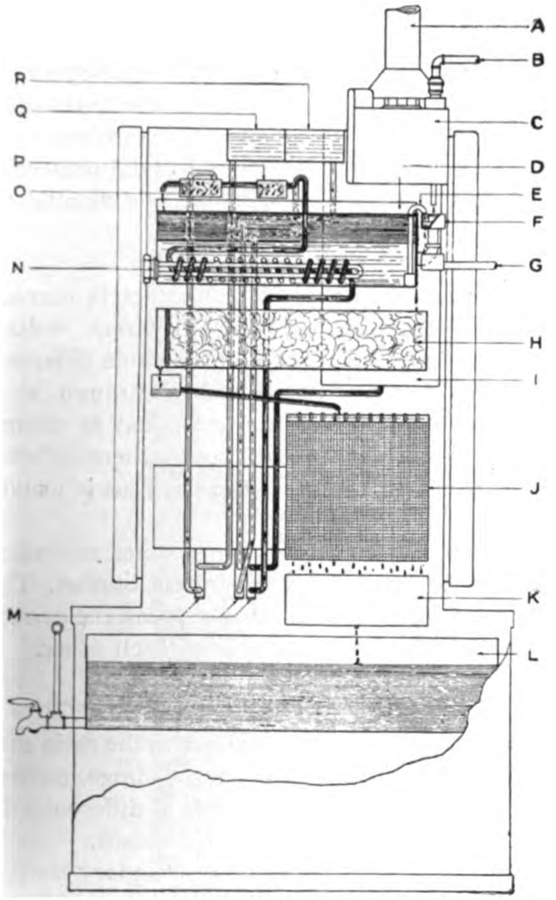


Fig. 2. **Sectional Diagram of the "Refinoroil," Showing Essential Elements of Refining Process**

A: Draft connection
B: Water inlet
C: Water-pressure control
D: Settling tank
E: Outlet for sludge
F: Interfacial level device
G: Sludge drain
H: Depth filter
I: Storage tank
J: Rectifying plates
K: Heat interchanger
L .Storage tank
M: Oil and reagent pumps
N: Immersion heater
O, P: Reagent mixing chambers
Q, R: Reagent reservoirs

While many oils react satisfactorily with the silicate alone some require an additional reagent to promote the peculiar effect of the former. This reagent, prepared under the trade name "Gelco," is therefore made a regular element of the process. These reagents are continuously metered into and mixed with the oil fed to the machine. The entire apparatus (Fig. 1) is assembled within a compact housing and is operated by the regular lighting current, which supplies heat and power. Fig. 2 and the accompanying legend provide the technical description in sufficient detail. In the reclaiming process two steps are involved: clarification and rectification. The oil, preheated, is mixed with the reagents in *O* and *P*. This develops a rapidly-settling oil-free sludge which carries the solid and other impurities. This sludge sinks into an underlying water layer in the settling tank (*D*) and is continuously evacuated at *E* into the drain through *G*, fresh water taking its place through an interfacial level device (*F*). A simple depth filter (*H*) of cheap materials removes any small fraction of the sludge which fails to precipitate in the clarifier. The clear oil next flows over the rectifying plates (*J*), which are swept by a draft of air preheated by the hot oil in the heat interchanger (*K*) and thence through *K* into the storage tank (*L*).

An outstanding feature of the machine is the fact that, as previously intimated, it is entirely automatic, so that the labor charge is negligible. From twenty to thirty minutes per day is all the attention that is required. This results in a cost of reclamation so low that a machine operating continuously will pay for itself in about six months under average costs of new oil and power; and gives, furthermore, a uniform quality of product, since this does not depend upon the care or skill of an operator.

The machine is at present manufactured in three sizes, having 24-hr. capacities of 8, 20, and 50 gallons respectively.

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*The Hilliard Corporation of Elmira, N. Y., are exclusive licensees under the patent rights of the General Electric Company, and are building and marketing the machine under the trade name "Refinoroil."

Relay Protection for Power Transformers

Cases Requiring Protection—Means Available for Relay Operation—Types of Relays—Application of Relay Protective Equipment

By J. W. DODGE

Central Station Engineering Dept., General Electric Company

THERE are several kinds of electrical faults which may occur in power transformers, against which it is desirable to provide relay protection. Among these are:

(1). Bushing flash-overs
(2). Winding-to-ground faults
(3). Faults between windings
(4). Faults between parts of same winding
(5). Faults at terminal boards or leads inside the tank.

With the improvements in design and materials used in modern power transformers, the present tendency towards coördination of transformer and transmission line insulation, and more effective use of lightning arresters, there is relatively little chance of an electrical failure. The cost and importance of large power transformers, however, merit the best relay protection available.

The best relay protection is probably that which provides very rapid and sure operation on heavy faults, such as a direct winding-to-ground failure, and also the sensitivity necessary to isolate the unit in case of a short circuit involving only a small portion of a winding. In the latter case rapid operation is not so important, as this type of fault usually requires quite some time to develop serious damage in the transformer.

It is also important that relays be applied to transformers in such a way that false relay operation on inrush magnetizing current will be avoided when starting the units, and so that the relays will select between internal faults and through current, with the types of current transformers usually available.

Differential Protection

Differentially-connected relays constitute the most common method of protection against faults in power transformers because they provide excellent protection against faults in the transformers and do not operate on through faults or overload current. Their operation depends on the fact that when a fault occurs in a transformer, the current flowing in the primary is not balanced by the current flowing out the secondary. The difference current is used to operate the differential relays.

A set of current transformers is used for each winding of the power transformers, with the ratios such that the secondary currents are approximately equal to the through current flow. Autotransformers are used to balance the secondary currents so that normally no current flows through the relay operating coils which are connected to receive the unbalanced portion of the current in the current transformer secondary circuit. In practice this differential protection scheme is handicapped by the following difficulties:

(1). Current Transformer Characteristics

Unless saturation is avoided, difference in current-transformer characteristics in the different voltage circuits, as to ratio, may cause appreciable difference in secondary currents at times of through short circuits, even though currents are equal at normal load. This is particularly troublesome where different types of current transformers are used, as is usually the case.

Unequal length of current transformer secondary leads causes difference in volt-ampere burden. This tends to result in an error in ratio between the current transformers being balanced against each other.

(2). Ratio Change by Taps on Power Transformers

On variable-ratio power transformers the ratio may be changed by taps on any of its windings, causing unbalance in the secondary currents of differentially-connected current transformers in its leads.

The unbalance or difference in secondary current from any of the foregoing causes increases with the through current. However, it does not increase greatly as a percentage of the through current; and therefore a relay whose operating current is a certain percentage of the through current (increasing as the through current increases) would allow a sensitive setting at low currents without danger of tripping on through faults.

(3). Magnetizing Current Inrush

Transformer magnetizing current inrush appears in the secondary of the current transformers as unbalanced current, of very much distorted wave shape. This magnetizing current may have a very high initial peak value, initially fully displaced from the symmetrical position, in which case the current decrement will be rapid during the first half-second; but the magnetizing current may not reach its normal value for several seconds.

The differential relays must have a sufficiently high current setting or time delay, or both, to prevent tripping on this inrush current.

Tests have shown that induction-type relays may be set far below the initial current inrush value without giving trouble due to operation on transformer starting current. In one case, for example, the relays would not operate on a magnetizing current inrush having an initial peak value of seven times the current setting (effective value) of the differential relays.

Overcurrent Relays

Overcurrent relays have been generally used for transformer differential protection. Instantaneous plunger types, set to pick up on a difference current of double full-load current, were commonly used for this purpose. Later, induction-type relays were employed set at full-load current (four amperes secondary) and a minimum time of 0.2 sec. This short time delay, together with the fact that the induction relay has an inverse time characteristic, allows a more sensitive setting on the induction type than with a plunger-type relay without false tripping due to magnetizing current inrush when the transformers are energized.

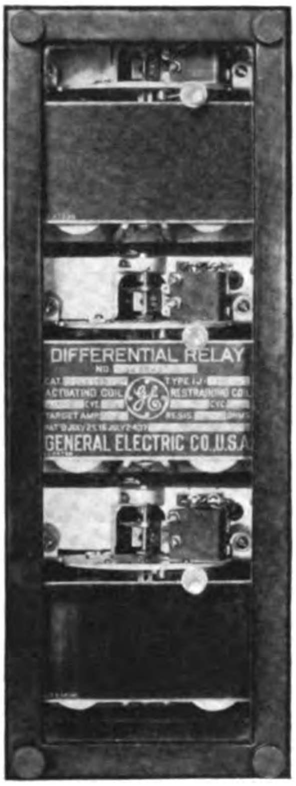

Fig. 1. Three-phase Percentage Differential-current Relay of the Induction Type

Percentage Differential Relay

A relay of the restrained percentage current differential type(1) has been developed and applied to transformer protection. This relay is of the induction type, similar to the ones previously applied to a-c. generator protection, having one operating winding and one restraining winding per phase.

The basis of this scheme is the same as the older method using overcurrent relays, connected to get the difference current between the high and low-side current transformer secondaries, with the refinement that the current setting is automatically maintained in proportion to the through current in the main unit. This is done by using the circulating current between the high and low-side current transformers in the restraining winding of the relay. This current is directly proportional to the through current of the main unit.

The percentage current differential relay is therefore simply an overcurrent induction relay with the addition of another torque-producing magnet excited by transformer load current, and opposing the main overcurrent magnet. Fig. 1 shows a relay of this type.

The restraining winding has 25 per cent of the turns of the operating winding, so that the difference current must be more than 25 per cent of the through current before the relay will operate. The relay is designed to operate on a difference current of two amperes with zero main current. This minimum setting can be increased to four amperes by change in spring tension, and this adjusting can be done in the field. Fig. 2 shows the relay characteristic curve. These relays are rapid in operation, the minimum time required to close the contacts being one-eighth of a second.

The percentage feature allows this much more sensitive current setting, as compared to the overcurrent relay, without false operation due to unbalance in current transformer secondary currents on through faults.

A large number of induction-type percentage current differential relays have been installed having an operating current of two amperes (equivalent to half of full-load current) and in no case has trouble been reported due to false tripping on starting current. There are also a considerable number of these relays being used which have a special low-current setting of one ampere (equivalent to one-quarter of full load) and in only one case has trouble been reported due to relay operation on starting current.

In special cases where the magnetizing inrush current is extremely high, or where a very sensitive setting of the differential relays is desired, a modification of the standard protective scheme can be used which automatically raises the current setting of the relays during the starting period.

Suitable resistors are placed in multiple with the relay coils to by-pass some of the unbalanced current during starting. A normally-closed time-delay-opening voltage relay is used in the circuit with these resistors to cut out the resistors after the transformer has become magnetized, thus restoring the normal sensitivity of the relays. It will be noted that this scheme does not prevent the differential relays from functioning during the starting period, but merely provides for more sensitive operation after starting than is otherwise possible.

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(1) Identified by the trade designation "Type IJ-7."

Fig. 3 is a schematic diagram of connections for the percentage differential current relay on a two-winding transformer with load-ratio control. One phase only is shown. The variation in transformer ratio is usually limited to plus or minus ten or twelve per cent. The percentage differential relay requires 25 per cent unbalance to operate it, and therefore provides adequate protection for variable ratio transformers without any additional complications. Fig. 4 shows the three-phase connections for two-winding transformer differential protection with this relay.

Bushing Flashovers

It is always desirable, where possible, to locate the current transformers outside of the transformers being protected by differential relays rather than in the transformer bushings. This includes the transformer bushings inside the protected zone, and the relays will give proper protection against a bushing flashover as well as for a ground in a winding. On high-voltage outdoor equipment it is usual to place these current transformers in the oil circuit breaker bushings on each side of the transformer bank, if such are available.

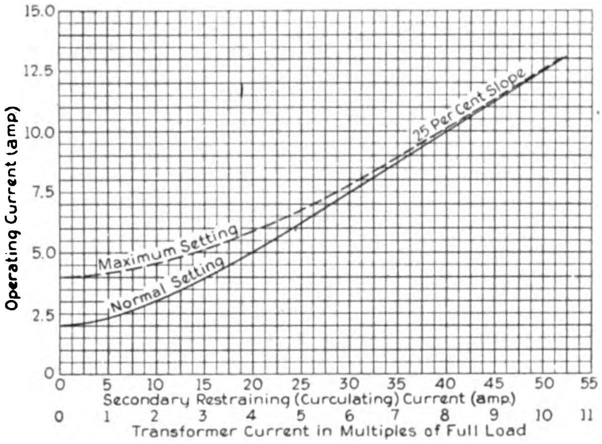

Fig. 2. Relay Characteristics for Transformer Differential Protection

Faults, Winding-to-ground

While a direct fault from winding to ground is extremely rare, owing to the very strong major insulation used in modern power transformers, the resulting fault current would be large, and it should be removed with all possible speed. The differential relay just described is very fast on high currents and in this respect is superior to the over-current induction relay, although not quite so fast as the plunger-type relay.

Faults Between Parts of Same Winding

A short circuit of a group of coils in a transformer winding causes fault current to flow in the short-circuited turns. This current does not necessarily appear in the leads of the faulted winding, but does produce ampere-turns on the core, causing an unbalance between input and output of the transformer. This unbalance causes current to flow through the differential relays. The amount of unbalance is not changed materially, whether the fault includes one turn or a considerable number of turns, so long as the faulted turns are confined to the same section of the winding.

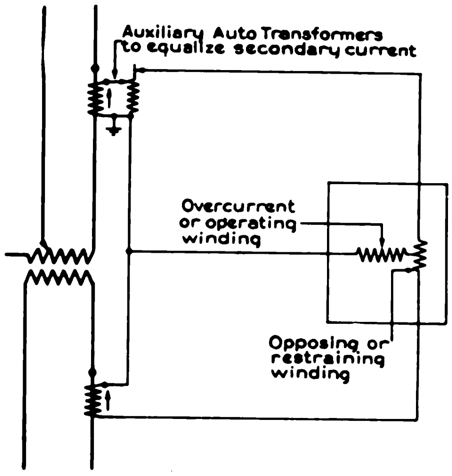
Auxiliary Auto Transformers to equalize secondary current
Overcurrent or operating winding
Opposing or restraining winding

Fig. 3. Diagram of Connections for the Application of Percentage Differential-current Relay to a Single phase of a Transformer Bank with Tap-changing Equipment

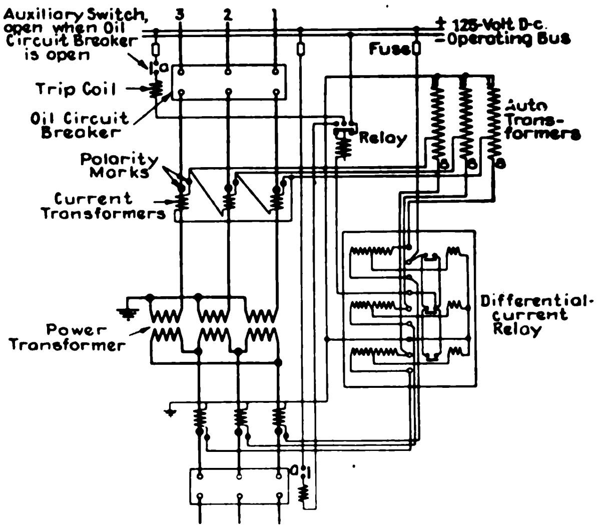
Auxiliary Switch, open when Oil Circuit Breaker is open
3
2
1
+ 125-Volt D-c.
− Operating Bus
Fuse
Trip Coil
Oil Circuit Breaker
Relay
Auto Trans-formers
Polarity Marks
Current Transformers
Differential-current Relay
Power Transformer

Fig. 4. Connections for the Application of Three-phase Relays to the Differential Protection of Power Transformers

In cases where this unbalanced current exceeds 50 per cent of the full-load current, the restrained differential relays provide effective protection. In cases where the initial fault current is too low to be detected by the relays, the fault must develop into a heavier one, involving more of the winding, before the relays will operate. If a more sensitive setting is required for this type of fault, a lower current setting can be used, provided the relays do not give trouble from tripping on starting current. The auxiliary relay and resistor scheme described earlier in this article can be used to advantage for such cases.

The percentage differential-current relay has a considerable advantage over the ordinary overcurrent relay as regards its sensitivity on turn-to-turn short circuits, since the current setting is 50 per cent of that used on induction overcurrent relays and 25 per cent of that used for plunger-type relays.

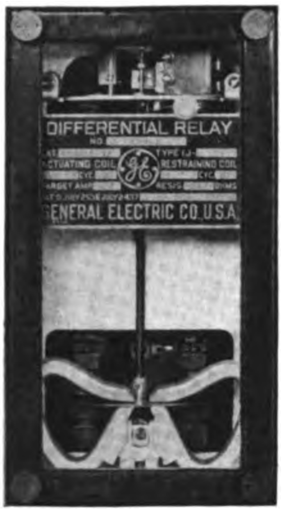
DIFFERENTIAL RELAY
GENERAL ELECTRIC CO. U.S.A.

Fig. 5. Single-phase Differential-current Relays for Use with Three-winding Transformers

Several schemes have been proposed to protect against single-turn short circuits in transformers; but none have been developed which are now considered equal to differential protection.

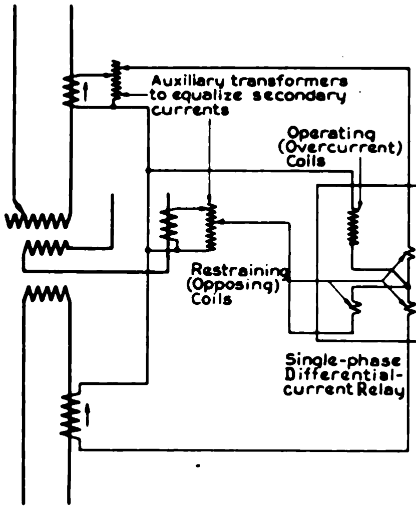
Auxiliary transformers to equalize secondary currents
Operating (Overcurrent) Coils
Restraining (Opposing) Coils
Single-phase Differential-current Relay

Fig. 6. Schematic Diagram (Showing One Phase Only) of the Application of a Single-phase Relay to a Three-winding Transformer with Tap-changing Equipment

Three-winding Transformers

A percentage differential relay has also been developed for the protection of three-winding power transformers. The relay is a single-phase model(2) of similar construction, having two elements, each containing an induction disk controlled by two electromagnets. The two disks are on the same shaft and operate a single set of contacts. Three of the magnets are restraining magnets and carry the currents from the current transformers in the three windings of the transformer individually. The fourth is the operating magnet and carries the difference of the currents in the three windings. Fig. 5 shows one of these single-phase relays. Fig. 6 is a schematic diagram of connections, showing one phase only. Fig. 7 shows the three-phase connections for three-winding transformer with load-ratio control, having restrained differential relay protection for the bank.

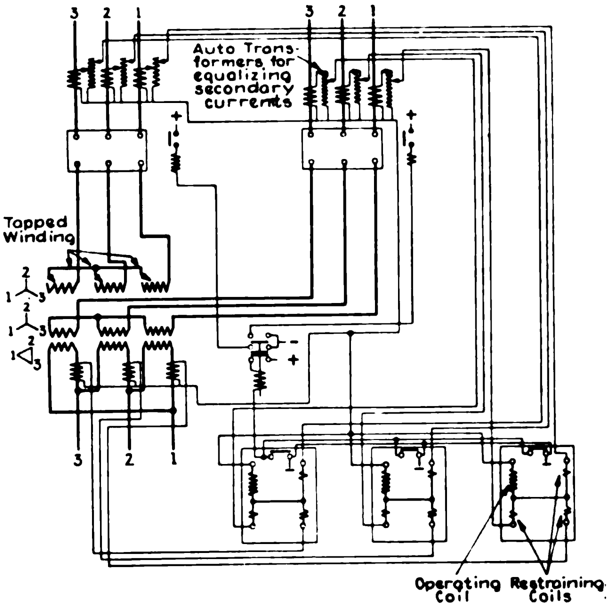
3 2 1
3 2 1
Auto Transformers for equalizing secondary currents
+
+
Tapped Winding
1 2 3
1 2 3
1 2 3
-
+
3 2 1
Operating Coil
Restraining Coils

Fig. 7. Diagram of Connections for the Application of Single-phase Relay to a Three-winding Transformer with Tap-changing Equipment

The single-phase relay has the same percentage feature as the three-phase type. By virtue of the fact that the torque of the electro-magnets depends only on the magnitude of current and is not affected by the direction of power flow in any winding, the relay will not operate unless the unbalance in current, representing difference between kv-a. input and kv-a. output of the transformer, exceeds 25 per cent of the through current. The characteristics of the single-phase relay are similar to those shown in Fig. 2 for the three-phase type. For transformers having four or more windings, a similar type of relay can be used.

Load-ratio Control Units

When a separate regulating transformer is used either with a power transformer bank, or for boosting voltage in a transmission line, special relay protection is necessary for the ratio control unit, in addition to the usual differential protection, if adequate protection is to be obtained.

Regulating transformers are usually limited to some 10 or 12 per cent of the capacity of the main circuit.

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(2) Identified by the trade designation "Type IJ-11."

and their reactance is such that a fault might occur in the exciting or regulating windings which would be several times the full-load current of the regulating unit, but not in excess of the normal load current of the series winding in the main circuit.

Ordinary differential or over-current protection would be sufficiently sensitive to give good protection for ground faults in the series winding of the regulating unit, because of its lower reactance, but would not be sensitive enough for detecting faults in the exciting and regulating windings.

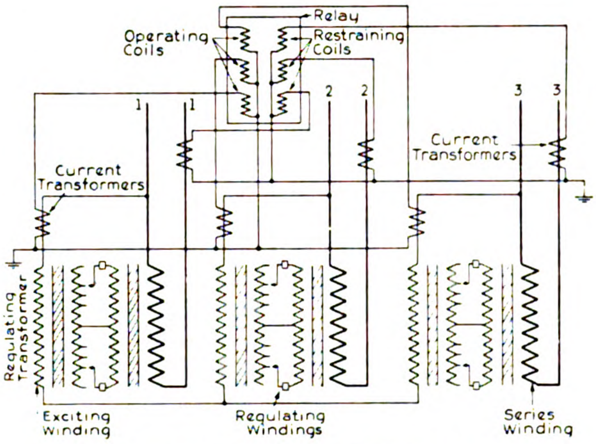

Fig. 8. Diagram of Connections for Restrained Overcurrent Relay Protection for Regulating Transformer

Over-current protection alone for the ratio control unit would not be desirable, as it would trip out on through faults.

A restrained over-current relay (3) has been developed for protection of these regulating units. It is connected as shown on Fig. 8, having the operating coils energized from current to the exciting winding of the ratio control unit, and restraining coils excited from main-line current to the transformer bank. This gives over-current protection for the ratio control unit restrained by the line current so as to prevent relay operation due to through faults.

The relay is usually arranged to operate at two times the full-load current in the exciting winding with zero restraint, with a range of setting down to full-load current by change in spring tension. This gives a range of setting which is usually high enough to prevent false tripping due to inrush current during switching operations, and sufficiently sensitive to provide protection against faults between adjacent taps in the regulating windings. The relay can be built for a lower operating current where desired.

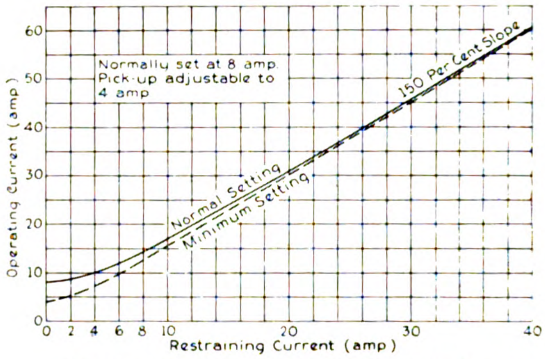

Fig. 9. Relay Characteristics for the Protection of Regulating Units

The restraining winding has one and one-half times the number of turns of the operating coil, so that the relay has a 150 per cent slope characteristic between operating and restraining current, as shown in Fig. 9.

This relay, together with the regular differential relay protection around the series winding gives the best protection available against internal faults.

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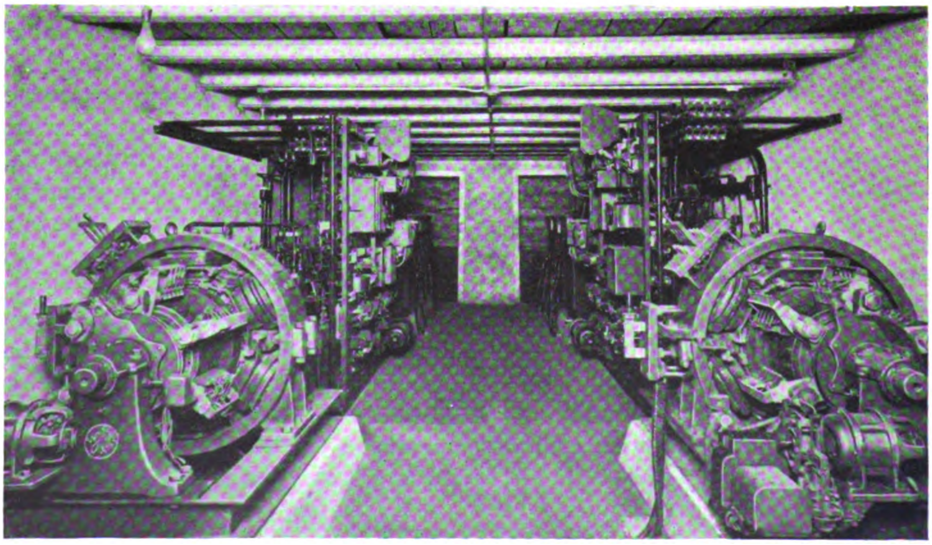
(3) Identified by the trade designation "Type IJ-12."

An Automatic Underground Substation



Diesel-electric Passenger Locomotive for New York Central Railroad

General Description—Cab Equipment—Engine and Auxiliaries—Electrical Equipment—Features of Operation and Control

By S. T. DODD
Railway Engineering Department, General Electric Company

A DIESEL-ELECTRIC locomotive was recently delivered to the New York Central Railroad for passenger service on its Putnam Division. This locomotive, shown in Fig. 1, is intended to handle the regular through passenger trains with the same running time as is now made by steam locomotives.

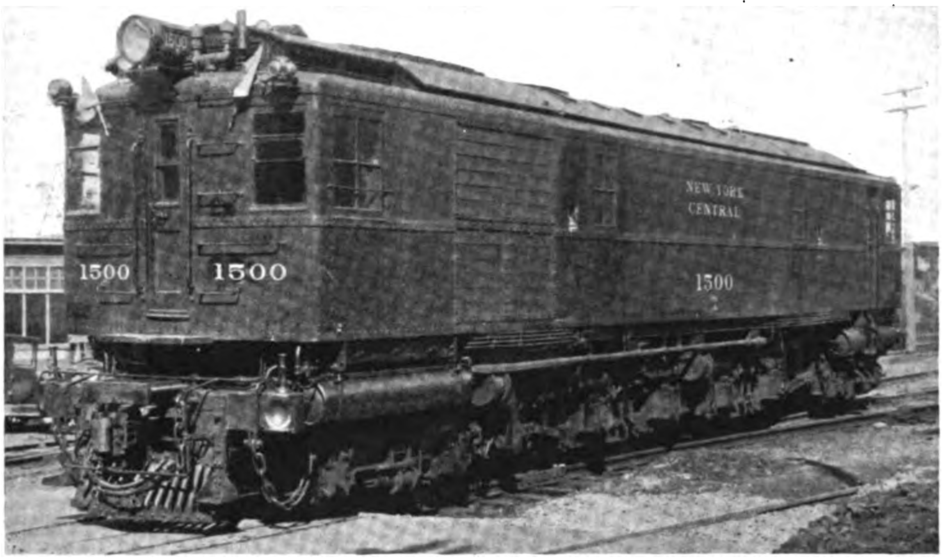


Fig. 1. New 900-hp. Diesel-electric Locomotive for Passenger Service on Putnam Division of New York Central Railroad

Weights and Dimensions

The principal dimensions and data relating to this locomotive are as follows:

Length inside of knuckles	59 ft. 4 in.
Height over cab	14 ft. 8½ in.
Width overall	10 ft. 0 in.
Total wheel base	49 ft. 4 in.
Rigid wheel base, driving	18 ft. 6 in.
Rigid wheel base, truck	6 ft. 2 in.
Diameter of driving wheels	44 in.
Weight in running order	361,500 lb.
Weight on drivers	185,000 lb.
Max. tractive effort at 25 per cent coefficient	46,300 lb.
Tractive effort, one-hour rating	28,000 lb.
Tractive effort, continuous	16,000 lb.

Cab and Running Gear

The running gear of the locomotive is of the 2-D-2 type, having eight driving wheels in the main frame and two two-axle trucks for guiding purpose. The rigid wheel base of the main frame is 18 ft. 6 in., with 44-in. driving wheels. The wheel base of each guiding truck is 6 ft. 2 in., with 30-inch wheels.

The main frame is formed of cast-steel side frames and cross ties supported on a system of equalizers and semi-elliptic springs resting on the journal boxes. Couplers are ARA Type D, with friction draft gear, mounted on the end frames.

The locomotive is furnished with air reservoirs of approximately 44,000 cu. in. capacity. Brakes are applied to all wheels and are operated by four 12 by 8-in. brake cylinders on the driving wheels and two 6 by 8-in. cylinders mounted on each of the guiding trucks.

The cab has four compartments: a central compartment for the main power apparatus; operating compartments (Fig. 2) at either end of the locomotive; and, connecting with one of the operating compartments, a smaller compartment for the traction motor fans and the motor generator set (Fig. 3) for charging the 32-volt battery from the 250-volt auxiliary circuit. On each side of this smaller compartment is a radiator for cooling the circulating water from the engine. In one of the operating compartments is located the train heating boiler. A water tank for maintaining water level above the engine cylinder heads is located on one of the interior partitions just below the roof. The main fuel oil tanks of a total capacity of 388 gallons are located below the cab floor, two at one end of the locomotive and one at the other.

In each operating compartment are located:

(*a*). A starting controller for starting the engine.

(*b*). A master controller for controlling the engine output, the generator excitation, and the motor combinations.

(*c*). Brake valves.

(*d*). An ammeter indicating motor current.

(*e*). A voltmeter indicating generator voltage.

(*f*). A distant reading thermometer indicating temperature of engine cooling water.

(*g*). Necessary gauge lamps for illumination of instruments.

(*h*). Lubricating oil pressure gauge.

Oil Engine

The engine which furnishes the power for this locomotive is a four-stroke cycle air injection Diesel engine (Fig. 4) of the 12-cylinder "V" type. The engine has the injection air compressor mounted at one end, and at the other end drives the generator through a special flexible coupling.

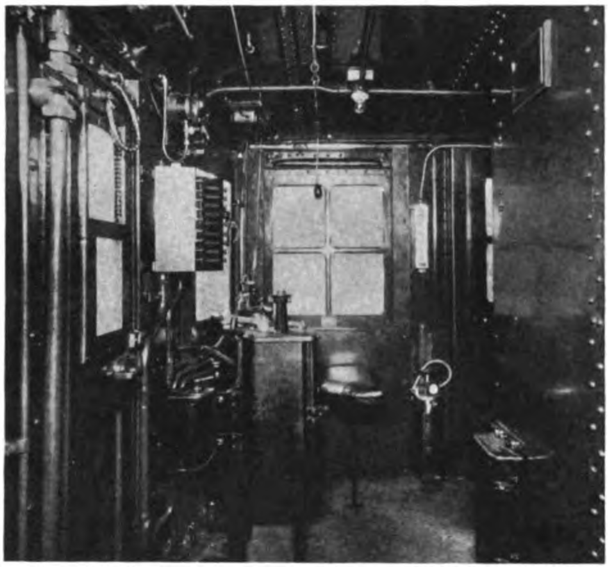


Fig. 2. Operator's Position at No. 1 End of Locomotive

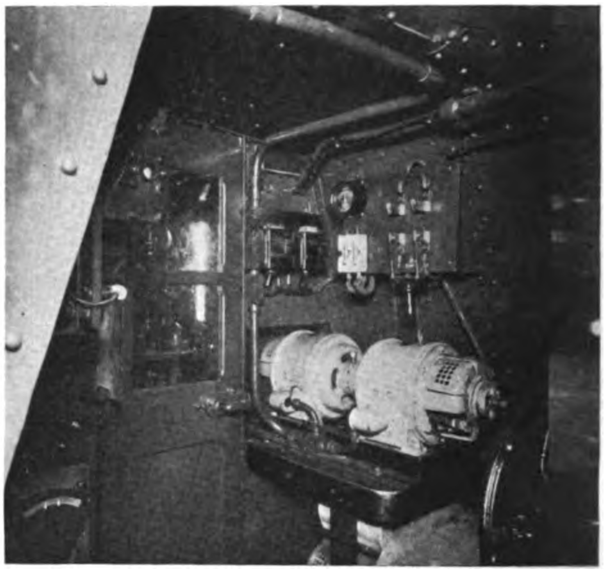


Fig. 3. Battery Charging Motor-generator Set and Control in Compartment of Locomotive

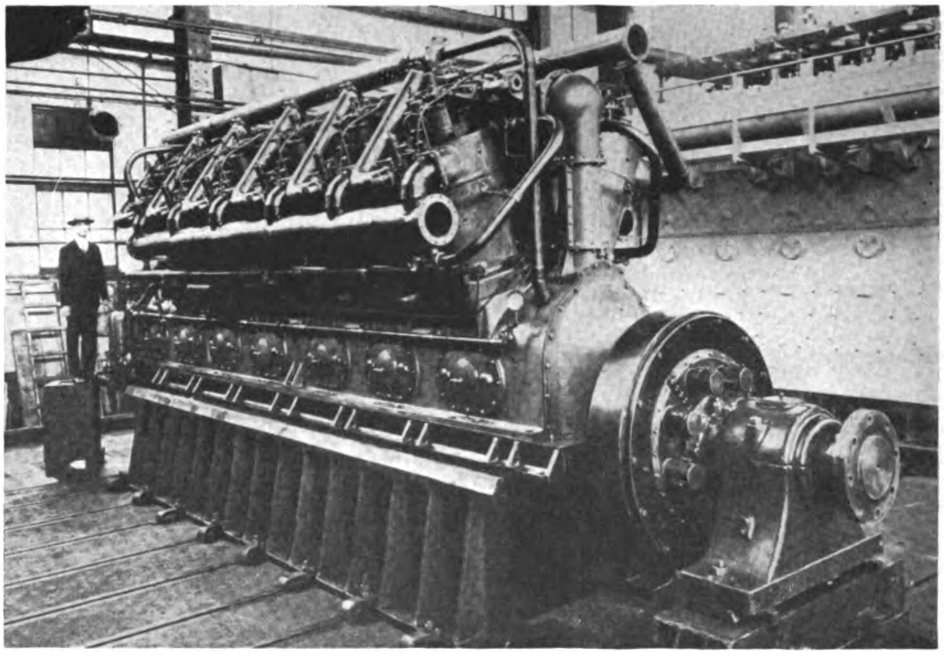


Fig. 4. Twelve-cylinder Diesel-engine for New York Central Locomotive Assembled on Testing Floor

The engine has cylinders 14 in. in diameter and a stroke of 18 in., a normal full-load speed of 310 r.p.m., and a full-load rating of 900 brake horsepower, with a 10 per cent overload capacity, the idling speed and the speed at intermediate powers being controlled by the control position, the electrical load, and the overspeed control.

The engine, generator and the whole cab structure (Fig. 5) are carried on a specially designed cast-steel underframe. The engine has a semisteel base with the bottom cast in to hold the lubricating oil. The engine base and the generator are securely bolted to the cab underframe. On the base is mounted a box frame of semisteel and on top of the box frame are mounted the engine cylinders. The engine cylinders are provided with removable heads, each head containing an exhaust valve, an air intake valve, fuel valve, and indicator connection to which a small safety valve is attached. On the heads for six of the cylinders there are also air starting valves.

The valves are actuated by light cast-steel rockers from a cam shaft located between the cylinders, which is driven by spur and bevel gears from the after end of the crank shaft.

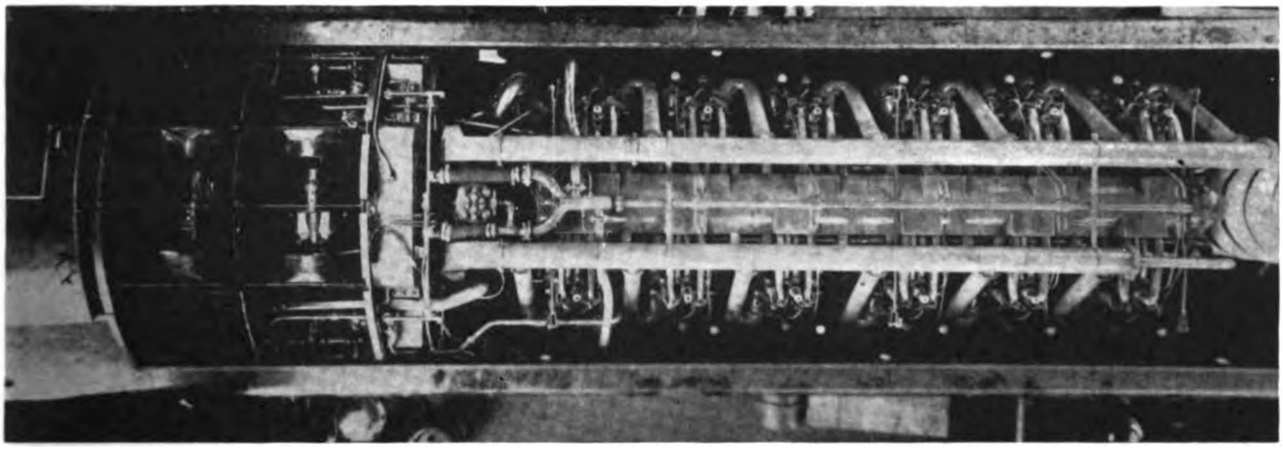


Fig. 5. Top View of Diesel Engine Installed in Cab of Locomotive

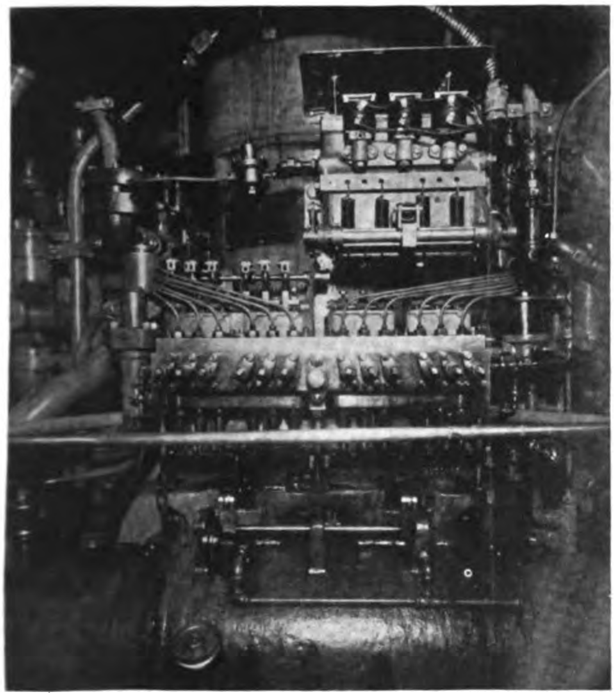


Fig. 6. Oil-injection Pumps and Electrically Operated Controlling Device for Engine

At the compressor end of the engine are mounted the fuel pumps (Fig. 6), a separate plunger being provided for each cylinder. These fuel pumps are under electrically operated control which regulates the amount of oil supplied to the cylinders, and consequently the torque which the engine can develop for this control setting. The fuel pumps are also connected to an overspeed control which prevents the speed of the engine from exceeding the proper limit.

At each side of the fuel pumps are mounted the water circulating pumps which circulate the water from the engine through the radiators. The lubricating pump, which takes the oil from the engine base, is located in the base itself and pumps the oil through the coolers, delivering it to the lubricating oil storage tank, from which another pump takes the oil and supplies it to the forced lubrication system. These pumps are all directly driven from the engine.

The exhaust manifolds are at each side of the engine, as shown in Fig. 5. Both manifolds go into one silencer (Fig. 7), and the pipe taking the gas from the silencer goes up through the roof of the locomotive.

If the engine took its air from the engine compartment, this amount of cold air coming into the compartment from outside in the winter would make the temperature undesirably low. Therefore the engine is supplied with air intake headers so that the engine takes its air from the compartment occupied by the traction motor blowers, which is connected by louvers in the roof with the outside air.

Cooling water for the engine is cooled in Modine-type radiators, half the radiating surface being placed in each side of the locomotive. A water tank with ample capacity is located at the top of the radiators so that the cooling system is filled with water at all times. To provide the cooling, four motor-driven Sturtevant fans draw air through the radiators and discharge it through shutters located on the roof.

Connected to the engine is a small rotary fuel pump which takes the oil from the main storage tanks, and delivers it to the fuel oil service tank in the roof of the locomotive. Surplus oil from this service tank goes through the overflow, back to the main storage tank. Oil from this service tank is supplied by gravity to the fuel pumps on the engine, and also to the burner of the heating boiler, shown in Fig. 8, used for heating the train. This is an Otis-Sawyer boiler of the same size and type now used on New York Central Type S electric locomotives. Two water tanks are provided for feed water for this boiler, and a small steam pump is provided in the engine compartment for supplying water.

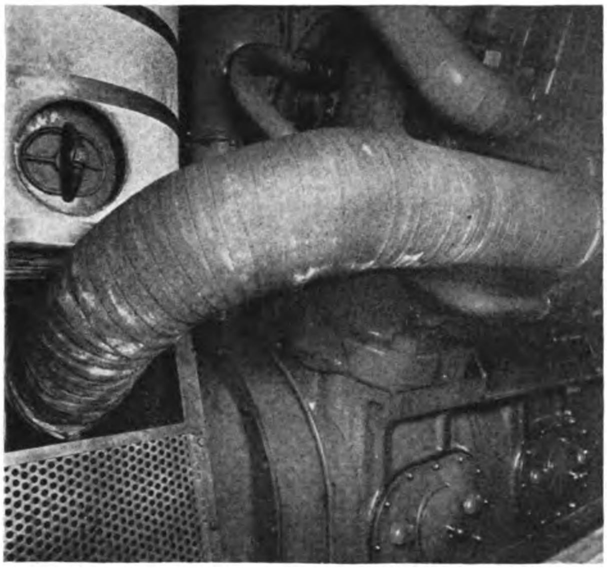


Fig. 7. Generator End of Engine, Showing Exhaust Pipe, Muffler, and Engine Base

Two air receivers suitable for 1000 lb. pressure are supplied for the storage of the air required for starting. These receivers are charged ordinarily from the main engine compressor while the main engine is running. This air is reduced to 350 lb. pressure at the engine when used for starting.

In the engine compartment there is a gasoline-engine-driven two-stage compressor for emergency service which can be used for charging the injection air receiver or the starting air receivers, if the pressure in these receivers has become too low because of leakage or overhauling while the engine is standing.

The engine output is remotely controlled by the master controller already mentioned. This master controller operates an output controlling device (Fig. 6) mounted on the engine, consisting of a number of pneumatically operated pistons, each controlled by a magnet valve. Each of these pistons establishes a definite position of the control arm which controls the time of closing of the suction valve for each plunger of the fuel pump. The wider open the control, the earlier the suction valves close so that more fuel is pumped to the engine cylinders and a correspondingly greater torque is developed by the engine. The position of the master controller thus determines the quantity of fuel supplied at each stroke, and the torque of the engine. The same device would be applicable to a second locomotive; and the coupling of the two control mechanisms on the same circuit makes possible a multiple-unit control for two locomotives.

Electrical Equipment

The electrical equipment includes a main generator (Fig. 9) and an auxiliary generator direct connected to the engine, four traction motors, control equipment, and electric auxiliaries, lights and instruments.

The main generator is of the multi-polar type carrying 10 main poles and 10 commutating poles. The magnet frame is fabricated from rolled steel with the halves welded together. The generator is of the two-bearing type, the weight of the armature being carried entirely on the armature bearings. The generator shaft is extended at one end to carry the auxiliary generator armature outside of the bearing, and at the other end to provide for a flexible coupling connecting it to the engine. There are three distinct field windings on the main poles:

(1). A small amount of differential series winding.
(2). A self-excited shunt winding.
(3). A separately-excited winding.

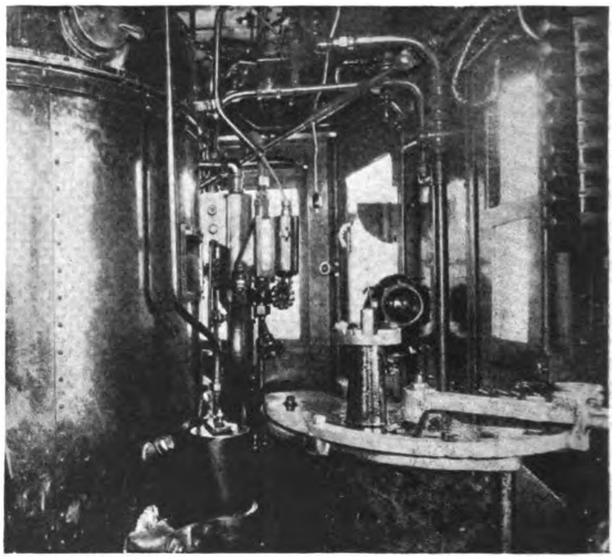


Fig. 8. Operator's Position at No. 2 End of Locomotive, Showing Boiler for Train Heating

The self-excited field furnishes the principal excitation for the generator. The separately-excited field receives current from the auxiliary generator. A resistance is provided for use in series with this field, so proportioned for each control position that the characteristics of the generator correspond to the required engine torque at each particular control position. By this means there are obtained, with the same speed, approximately equal increments of tractive effort at the driving wheels for each controller step; or, with the same tractive effort, equal increments of speed. The controller thus establishes a definite engine torque, and simultaneously a setting of the field strength which is most desirable at this output.

The auxiliary generator mounted on an extension of the main generator shaft supplies the separate excitation at 250 volts for the main generator, as well as power for the auxiliaries. This generator is so regulated that it maintains a practically constant voltage throughout the range of engine speeds.

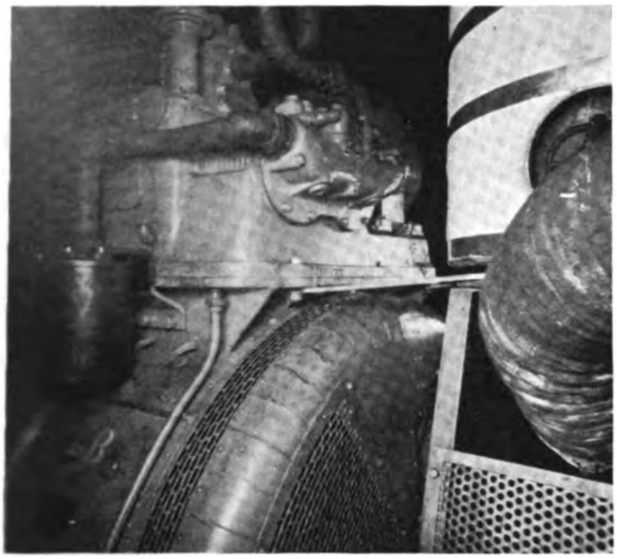


Fig. 9. Generator End of Engine, Showing Main Generator and Compressor Units

Four GE-286, 600-volt, single-geared, commutating-pole traction motors, one mounted on each driving axle, drive the locomotive through gearing with a reduction of 69/20. These motors and gears are the same as those used on the New York Central Class R electric road freight locomotives.

Three running combinations of the traction motors are used, *viz.*, series-parallel, parallel, and parallel with reduced fields. The various motor combinations are obtained through electro-pneumatic contactors and a reverser actuated by the reverse handle on the master controller. The transfer from series-parallel to the parallel position is effected by interlocking between contactors and by cushioning resistors so that the change is made from one connection to the other with full torque on the engine and without reducing the engine speed during transition

Compressed air for the brakes is supplied by a motor-driven air compressor having a displacement of 100 cu. ft. per min. This compressor is located above the main generator in the main cab.

Power for the compressor, blowers, and motor-generator set is supplied from the auxiliary generator. The field of this generator is excited at 32 volts and is regulated by a carbon-pile regulator to maintain its terminal voltage at 250 volts through a range of engine speeds from the idling speed up to full speed.

Provision is made for operating blowers either in series or parallel connection. These combinations are controlled by master switches in the operating cabs. This feature is especially desirable for the radiator fans because it provides a means of obtaining reduced radiation in the winter months with a consequent saving in power. The starting and stopping of these fans is automatically accomplished by means of a thermostatic control device.

The 32-volt supply for the lighting and control circuits is obtained from a motor-generator set driven from the 250-volt auxiliary circuit. A carbon-pile regulator in the generator field of this set maintains a constant voltage for the auxiliary circuits, as well as for charging a 32-volt 150-ampere-hour storage battery. This battery supplies the lighting circuits when the engine is not in operation, as well as the control circuits.

Cab lights are provided in both the operating and engine compartments. Drop-lights in the engine compartment are provided for inspection while in service. All lights, including the headlights, are supplied from the 32-volt circuit. A dimming resistance is provided for each headlight.

In addition to the meters located at each operating position, there is also provided an integrating watt-hour meter connected to measure the main generator output. An ammeter also indicates the amount of charge or discharge in the storage battery circuit.

Train line couplers at each end of the locomotive permit the operation of two locomotives in multiple unit with the control of both from any one of the operator's positions.

For this locomotive the American Locomotive Company designed and built the mechanical equipment, including cab and running gear; the General Electric Company furnished the electrical equipment; and the McIntosh & Seymour Corporation supplied the oil engine and completed the installation of the equipment.

Industrial Electric Heating

PART X: FURNACE ATMOSPHERES (Cont'd)

By N. R. STANSEL and C. DANTSIZEN
Industrial Engineering Dept. Research Laboratory
General Electric Company

IN the use of a hydrogen atmosphere as an agent for the reduction of iron oxide in the heat treatment of steel we have an attendant reaction between the hydrogen and the carbon in the steel. This reaction is reversible, thus:

$$CH_4 \rightleftarrows 2\,H_2 + C \tag{35}$$

and goes to equilibrium between the quantities of hydrogen and methane which can exist together in the presence of carbon. In the case of carbon in steel, if the reaction proceeds more rapidly to the left than to the right, carbon is removed from the steel (decarburization); if more rapidly to the right, because of an excess of methane in the system, the carbon derived from dissociation of methane will go into solution in the iron (carburization), provided that the iron is not already saturated with carbon at the temperature of the process. If the two reaction velocities are equal (the equilibrium condition) there will be no change in the carbon content of the steel, *i.e.*, under this condition the atmosphere of the heating chamber is neutral with respect to the carbon in the steel. At equilibrium we have

$$K_t = \frac{(p_{H_2})^2 \times p_C}{p_{CH_4}} \tag{36}$$

in which for a given temperature t

K_t = the dissociation constant of methane
p_{H_2} = the partial pressure of hydrogen
p_C = the partial pressure of carbon vapor
p_{CH_4} = the partial pressure of methane.

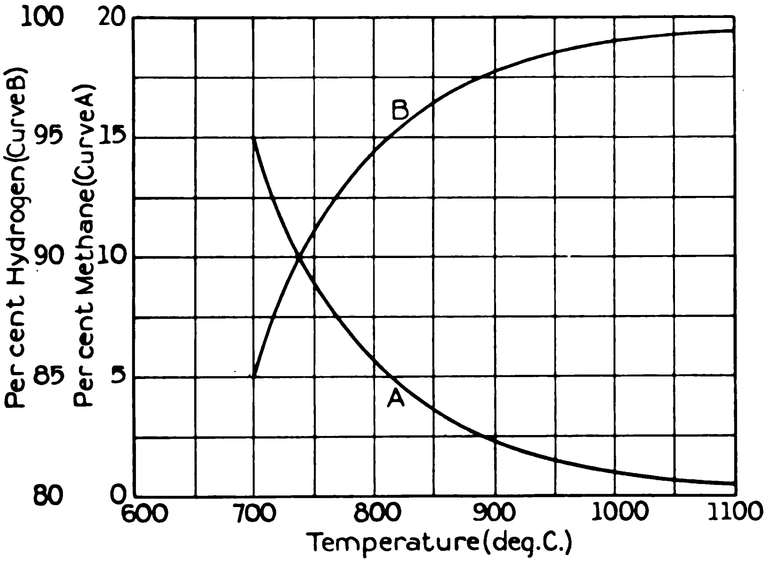


Fig. 145. Percentages of Methane and Hydrogen in Equilibrium with Graphite at Various Temperatures

Curve *A*: Methane Curve *B*: Hydrogen

At any given temperature, at equilibrium with pure carbon (graphite), in the system methane—hydrogen—carbon vapor—graphite, the partial pressure of carbon vapor is equal to the vapor pressure of graphite. The equation for the equilibrium is

$$\frac{K_t}{p_C} = \eta_t = \frac{(p_{H_2})^2}{p_{CH_4}} \tag{37}$$

in which

η_t = the equilibrium constant characteristic of graphite in the system for the given temperature t.

The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs*	*Equations*	*Examples*	*Tables*	*Footnotes*
Part I	Oct. 1927, p. 488	1 to 32	(1) to (8b)	1 to 3	I to III	(1) and (2)
Part II	Nov. 1927, p. 551	24 to 43	(9) and (10)	4 to 6	IV to VII	(3) to (13)
Part II	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	———	X to XX	(16) to (26)
Part V	Apr. 1928, p. 204	74 to 83	(15) to (21)	12 and 13	XXI to XXIII	(27) to (29)
Part VI	Sept. 1928, p. 485	84 to 99	———	14	XXIV to XXIV	(30) to (35)
Part VII	Oct. 1928, p. 560	100 to 113	(22) to (24)	15	XXVII and XXVIII	(36) to (41)
Part VIII	Dec. 1928, p. 662	114 to 138	(25)	———	———	(42) to (47)
Part IX	Mar. 1929, p. 162	139 to 144	(26) to (34b)	———	XXIX to XXXIII	(48) to (59)

In the case of equilibrium with the carbon in steel, the partial pressure of carbon vapor is equal to the vapor pressure of carbon in solution in iron. This vapor pressure varies with the degree of carbon saturation and for any given temperature is a maximum at carbon saturation, at which it is equal to the vapor pressure of graphite. Carbon saturation then is the upper limit, for any given temperature, of p_C in Equation (36); that is, p_C = the vapor pressure of graphite. With reference to carbon in steel we will write

η_t' = the equilibrium constant characteristic of the degree of carbon saturation of the steel for the system methane—hydrogen—carbon vapor and carbon in solution in iron for the given temperature (t).

Whatever may be the degree of carbon saturation, the value K_t in Equation (36) is constant for a given temperature and at equilibrium (in the system methane—hydrogen—carbon vapor and carbon in solution in iron) p_C is equal to the vapor pressure of the carbon in solution in iron; hence the lower the original percentage of carbon in a steel, the lower is the quantity of methane in the system at equilibrium. Since with decarburization the vapor pressure of carbon in solution in iron decreases, the value of the equilibrium constant (η_t') is that corresponding to the degree of carbon saturation at equilibrium.

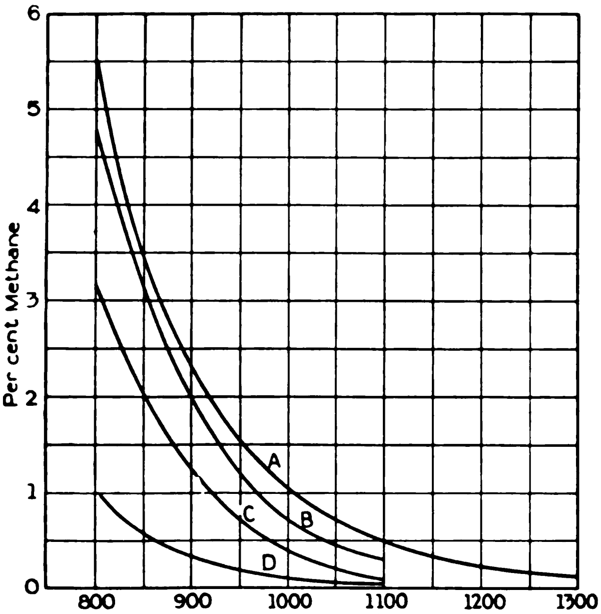


Fig. 146. Percentages of Methane in Hydrogen-methane Mixtures in Equilibrium with Carbon in Solution in Iron for Three Steels of Different Carbon Contents

Curve *A*: Curve *A* from Fig. 145
Curve *B*: 0.95 per cent carbon steel
Curve *C*: 0.59 per cent carbon steel
Curve *D*: 0.18 per cent carbon steel

This equilibrium condition is similar to the equilibrium condition for a metallic oxide—metal—hydrogen—oxygen—water vapor system, in that p_C and p_{CH_4} of Equation (36) correspond respectively to p_O, and p_{H_2O} of Equation (27); and the vapor pressures of carbon in solution in iron corresponds to the dissociation pressure of the metallic oxide. However, as previously noted, the vapor pressure of carbon in solution in iron for a given temperature varies while the dissociation pressure of a metallic oxide for a given temperature is constant.

Values of the percentages by volume of methane (and of hydrogen) at equilibrium for given temperatures in the system methane—hydrogen—carbon vapor—graphite are applicable in the case of carbon in solution in iron only for a steel saturated with carbon at the given temperature. The chart for this condition is given in Fig. 145; Curve *A* being the percentage of methane and Curve *B* the percentage of hydrogen. The values of Curve *A* are those given by Sykes.(60)

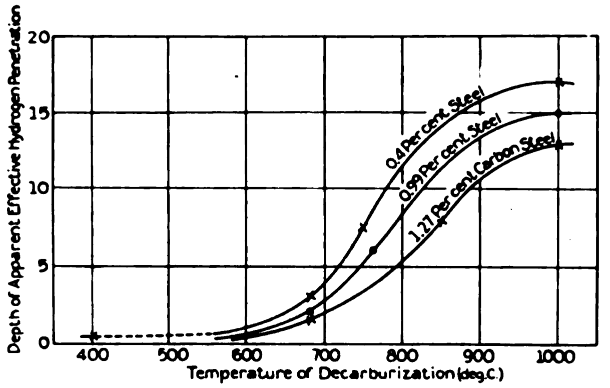


Fig. 147. Effect of Temperature on Apparent Depth of Hydrogen Decarburization with a Constant Time-factor of 12 Hours

For unsaturated steels there will be corresponding curves for the methane components of the systems below Curve *A* and corresponding curves for hydrogen above Curve *B*. The methane-temperature equilibrium curves for three cases of unsaturated steels determined by Sykes(60) are given in Fig. 146. (The equilibrium curve for the system methane—hydrogen—carbon vapor—graphite, Curve *A* of Fig. 145, is added for convenient reference.) These determinations were made with natural gas, with an average content of 80 per cent methane. The values given in Fig. 146 correspond to 100 per cent methane.

In the case of steel in a hydrogen atmosphere which is maintained at an elevated temperature the decarburizing reaction will continue, assuming that the methane is not removed as formed, until there is equilibrium established among the three partial pressures of hydrogen, methane and carbon in solution in iron. Conversely, if an excess of methane, *i.e.*, a methane content above the equilibrium value for that temperature and steel, is put into the system, the steel will be carburized, the limit being carbon saturation for the given temperature.

The chart of Fig. 147 is reproduced from a study of hydrogen decarburization of steel by Austin.(61) Three steels having the carbon contents 0.4 per cent, 0.99 per cent, and 1.27 per cent were used. Austin states with reference to the curves of Fig. 147:

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(60) "Carburizing Iron with Mixtures of Hydrogen and Methane," *Trans. A. S. S. T.*, Vol. 12, p. 737.

(61) "Hydrogen Decarburization of Carbon Steels with Considerations on Related Phenomena." *Jour. Iron and Steel Inst.*, Vol. 105, p. 93.

"The smooth curves, which have been drawn through points representing the respective steels, give graphically an idea of the relative apparent effective penetrative power of hydrogen gas with regard to elimination of carbon from carbon steels between the temperature limits investigated. It may at once be emphasized that this has no reference to quantity of carbon removed, nor to the complete decarburization zones of the steels, though at low temperatures the two quantities, effective hydrogen range and range of complete decarburization, are coincident. The figure is given as an attempt to illustrate qualitatively the effect of temperature, given a constant time factor, on the maximum depth from the surface at which a decrease in the original carbon content obtains. It indicates that the "velocity" of the decrease is very slow below the eutectoid temperature, whilst above this a marked and rapid increase is noticed. The increase begins to fall off somewhere about 900° C., and probably, in conformity with the previously cited results of E. D. Campbell,⁽⁶²⁾ the velocity reaches a point of inflection at about 1000° C., after which the acceleration assumes a negative value."

It seems probable to the writers that the increasing dissociation of methane with rising temperature is responsible for the falling off at around 900 deg. C. of the action noted in the quotation.

It appears to be extablished that the presence of water vapor in artificial atmospheres used in connection with the heat treatment of steel promotes decarburization and inhibits carburization. For example, Sykes (60) found that with a mixture of hydrogen and natural gas containing initially 0.6 per cent water vapor by volume at 32 deg. F. the amount of methane in this atmosphere at equilibrium was several times that required for equilibrium with initially dry gas under otherwise the same conditions. This is illustrated by the chart of Fig. 148 from data by Sykes.

Carbon monoxide is the second of the two gases available for the reduction of metallic oxides by heat. In this case the oxygen liberated from the oxide by heat combines with the carbon monoxide to form carbon dioxide and thus a partial pressure of oxygen lower than the dissociation pressure of the oxide at the given temperature is maintained over the oxide surface.

In the case of the reduction of iron oxide through the use of an artificial atmosphere of carbon monoxide the complete reduction of ferro-ferric oxide is expressed by the equation

$$Fe_3O_4 + 4\,CO \rightleftarrows 3\,Fe + 4\,CO_2 \qquad (38)$$

This reaction is progressive, thus:

$$Fe_3O_4 + CO \rightleftarrows 3\,Fe\,O + CO_2 \qquad (38a)$$

$$Fe\,O + CO \rightleftarrows Fe + CO_2 \qquad (38b)$$

The carbon dioxide is dissociated into carbon monoxide and oxygen, thus:

$$2\,CO_2 \rightleftarrows 2\,CO + O_2 \qquad (39)$$

and at equilibrium in the system iron oxide—iron—carbon monoxide—oxygen—carbon dioxide we have

$$K_t = \frac{(p_{CO})^2 \times p_{O_2}}{(p_{CO_2})^2} \qquad (40)$$

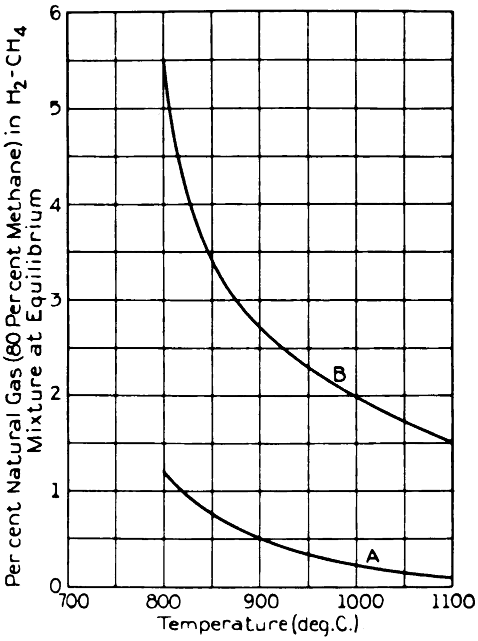

Fig. 148. Effect of Water Vapor on the Percentage of Methane in a Hydrogen-methane Mixture in Equilibrium with Carbon in Solution in Iron

Curve *A:* Gas mixture deoxidized and dried
Curve *B:* Gas volume containing 0.6 per cent by volume of water vapor at 32 deg. F.

in which for temperature *t*

K_t = the dissociation constant of carbon dioxide
p_{CO} = the partial pressure of carbon monoxide
p_{O_2} = the partial pressure of oxygen
p_{CO_2} = the partial pressure of carbon dioxide.

At equilibrium in this system, the partial pressure of oxygen is equal to the dissociation pressure of the oxide; and we have from Equation (40)

$$\left[\frac{K_t}{p_{O_2}}\right]^{\frac{1}{2}} = \eta_t = \frac{p_{CO}}{p_{CO_2}} \qquad (41)$$

in which

η_t = the equilibrium constant characteristic of the given oxide in this system at the given temperature (t).

The relation between the equilibrium constant of Equation (41) and temperature for the final stage of the reaction of Equation (39) from data by Eastman and Evans(59) is shown by Curve *A* of Fig. 149. The corresponding relations between the percentages of carbon monoxide and temperature and between percentages of carbon dioxide and temperature are shown by Curves *B*, and *C* respectively. For example, at 900 deg. C. the equilibrium condition, *i.e.*, equal reaction velocities, and hence in effect neither reduction nor formation of oxide is attained with a heating chamber atmosphere composed of 68 per cent carbon monoxide and 32 per cent carbon dioxide. Thus there will be continuous reduction of iron oxide at a temperature of 900 deg. C., if the carbon monoxide content of the heating chamber atmosphere is maintained above 68 per cent. Conversely, this atmosphere can be made oxidizing at 900 deg. C. by raising the carbon dioxide content above 32 per cent.

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(62) "Decarburization of Steel with Hydrogen," *Jour. Iron and Steel Inst.*, Vol. 100, p. 406.

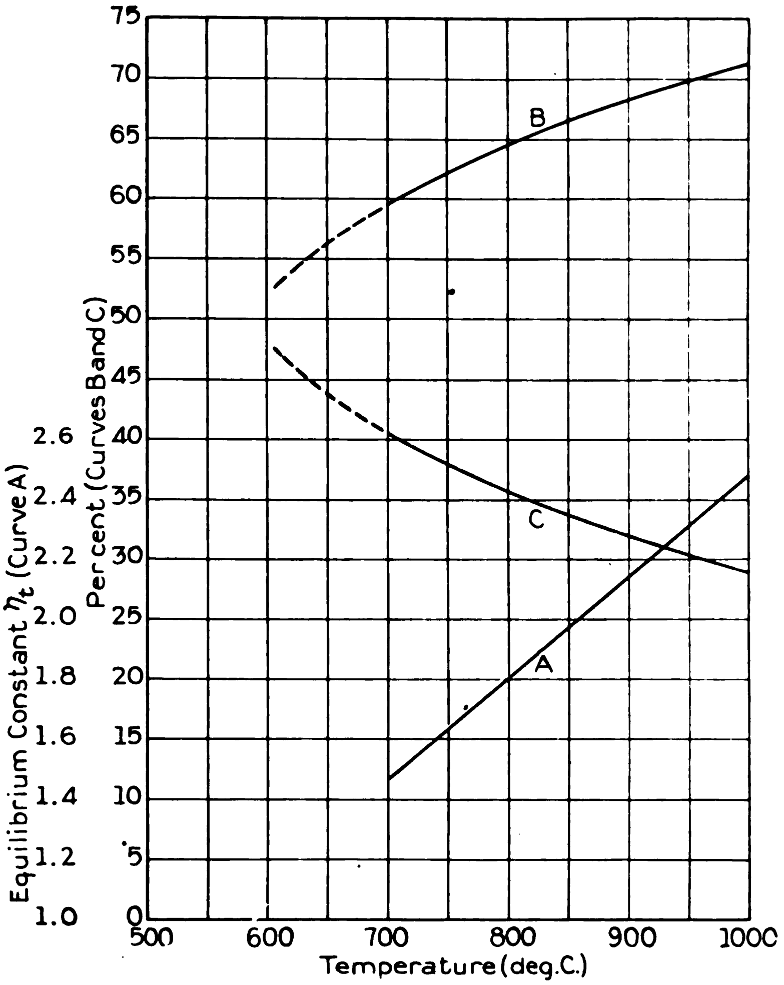

Fig. 149. Percentages of Carbon Monoxide (Curve *B*) and of Carbon Dioxide (Curve *C*) in Equilibrium with Iron Oxide at Various Temperatures. The relation between the equilibrium constant and temperature is shown in Curve *A*

The general statement with reference to Fig. 149 is that if iron oxide is present in the heating of steel in an atmosphere of carbon monoxide it is reduced if the carbon monoxide component of the heating chamber atmosphere is maintained above the equilibrium value as shown by Curve *B* for the temperature of the heat treatment process; and that if the carbon monoxide content is less than this value the reaction is in the reverse direction, *i.e.*, the iron is oxidized. Hence an artificial atmosphere of this kind can be made reducing, neutral, or oxidizing at any given temperature by controlling the proportions of the component gases.

It will be noted that the higher the temperature of the heating chamber the higher is the percentage of carbon monoxide at equilibrium. Also that if an artificial atmosphere of this kind is effective in oxide reduction at a given temperature it will be effective at any lower temperature provided that the lower temperature is high enough to give a reaction velocity sufficient for the need.

The most effective agent for the reduction of metallic oxides is the substance whose oxidation product is the least dissociated at the temperature of the process. The per cent dissociation of water vapor, the oxidation product of hydrogen, is given in Table XXIX. The per cent dissociation of carbon dioxide, the oxidation product of carbon monoxide, as determined by Langmuir(61) is given in Table XXXIV. A comparison of the effectiveness of these two gases for metallic oxide reduction at a given temperature is thus obtained by reference to these two tables. This is better shown in graphic form in Fig. 150. It will be noted by reference to this chart that at about 750 to 800 deg. C., the two gases are equally effective as metallic oxide reducing agents. At lower temperatures carbon monoxide is more effective while above 800 deg. C., hydrogen is the more effective reducing agent. Schenck(63) gives from other data 867 deg. C., as the temperature at which these two gases are equally effective in metallic oxide reduction.

TABLE XXXIV

Deg. F.	Deg. C.	Deg. K.	Per Cent Dissociation of Carbon Dioxide
1340	727	1000	0.000020
1700	927	1200	0.000930
1880	1027	1300	0.00407
2060	1127	1400	0.01460
2240	1227	1500	0.04360
2420	1327	1600	0.110
....	....	1700	0.260
....	....	1800	0.546
....	....	1900	1.04
....	....	2000	1.84
....	....	2200	5.00
....	....	2500	15.60
....	....	3000	48.50

Carbon monoxide under the conditions of its use as an agent for the reduction of iron oxide by heat undergoes dissociation, the products of the reaction being carbon dioxide and pure carbon. The reaction is reversible and for any given temperature goes to equilibrium between carbon monoxide and carbon dioxide. This reaction, which is attendant to the reaction of Equation (38), is written

$$2\,CO \rightleftarrows CO_2 + C \tag{42}$$

and at equilibrium we have,

$$K_t = \frac{p_{CO_2} \times p_C}{(p_{CO})^2} \tag{43}$$

in which for temperature t

K_t = the dissociation constant of carbon monoxide

p_{CO_2} = the partial pressure of carbon dioxide

p_C = the partial pressure of carbon vapor

p_{CO} = the partial pressure of carbon monoxide.

Values of the percentages by volume of the two gases, carbon monoxide and carbon dioxide, for equilibrium with graphite(64) by Rhead and Wheeler(65) are given in Table XXXV.

In the case of equilibrium for the reaction with carbon in solution in iron, the values of Table XXXV apply only to carbon saturation. (This is parallel to the case of the methane reaction described in preceding paragraphs.) For unsaturated steels there will be for each temperature a definite value of the equilibrium constant corresponding to the degree of carbon saturation at equilibrium; *i.e.*, for the system comprised of carbon monoxide, carbon dioxide, carbon vapor, carbon in solution in iron, and iron (the iron serves as the necessary catalyst for this reaction) at equilibrium, the partial pressure of carbon vapor is equal to the vapor pressure of carbon in solution in iron and we have

$$\frac{K_t}{p_C} = \eta_t' = \frac{p_{CO_2}}{(p_{CO})^2} \tag{44}$$

in which

η_t' = the equilibrium constant characteristic of the degree of carbon saturation at equilibrium for the system noted at temperature t.

Equilibrium values of the component gases for the reaction of Equation (42) in equilibrium with carbon in solution in iron in the case of unsaturated steels have not been determined. However, for our purpose we can use the values given in Table XXXV without serious error.

The dissociation of carbon monoxide tends to interfere with the function of that gas in the reduction of iron oxide. Thus, referring to Fig. 149, the production of of carbon dioxide (by the dissociation of the carbon monoxide) may carry the proportion of carbon dioxide above the equilibrium value for a given temperature as shown by Curve *C*, the result being oxidation of the iron instead of the intended reduction of the oxide. These reactions are cumulative and will be referred to again in the consideration of the effect of pressure on gas reactions.

TABLE XXXV

Temperature, Deg. C.	Per Cent CO	Per Cent CO_2
850	93.77	6.23
900	96.60	3.40
950	98.35	1.65
1000	99.19	0.81
1050	99.55	0.45
1100	99.75	0.25

It was noted in Part IX of this serial, with reference to the dissociation of mercuric oxide, that a so-called inactive gas can be mixed with an active gas to form an artificial atmosphere; and in practice this is frequently done, nitrogen being the diluent in general use for this purpose. Both hydrogen and carbon monoxide are inflammable and the mixing of nitrogen with either of these gases to form artificial atmospheres is primarily to reduce the quantity of inflammable gas in the heating chamber. In some cases nitrogen may be of lower cost than the active gas and in such cases the mixing is a measure of economy. The practical method of determining the proportions of a mixture of active and inactive gases in a given case is the gradual reduction of the amount of active gas from charge to charge until the minimum amount of that component of the mixture for a satisfactory result is determined. The proportions of the gas mixture are individual in each case. For example, in one furnace used for the heat treatment of steel a mixture of 85 per cent nitrogen and 15 per cent hydrogen is used; while in another furnace of different dimensions but used for the same class of work the artificial atmosphere is 50 per cent nitrogen and 50 per cent hydrogen. At a third and similar installation nitrogen is not available and the atmosphere of the heating chamber in hydrogen alone.

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(63) *The Physical Chemistry of Metals*, p. 613, John Wiley & Sons, Inc.

(64) Lewis and Randall (*Thermodyanmics*, p. 573) state with reference to the work of Rhead and Wheeler: "In their experiments wood charcoal was used, which was treated with chlorine at 1000 deg. C. for 24 hours, and later with other gases for several days at the same temperature, so that we may assume that the carbon was, at least on the surface, in the form of graphite."

(65) "The Effect of Temperature on the Equilibrium $2\,CO \rightleftarrows CO_2 + C$." *Jour. Chem. Soc.*, Vol. 97, p. 2178, and Vol. 99, p. 1140.

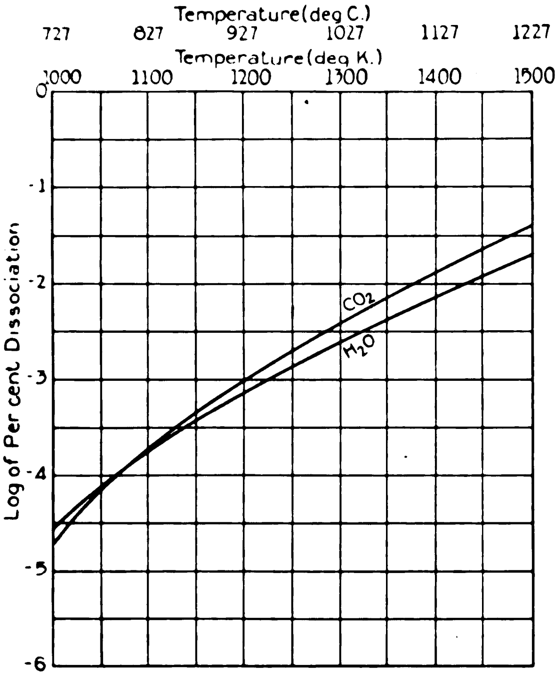

Fig. 150. Comparison of the Effectiveness of Hydrogen and Carbon Monoxide as Agents for the Reduction of Metallic Oxides by Heat as Indicated by the Dissociations of Water Vapor and Carbon Dioxide

Before going further with the consideration of artificial atmospheres with respect to the charge it may be well to refer again to the activity or passivity, as the case may be, of the gases in the heating chamber towards the material of resistors mounted in the heating chamber. The general conditions are noted in Part II (page 556) of this serial. Each material used in resistor construction must of course be considered individually for each gas. Some observations regarding this relation follow.

The nickel-chromium alloy resistors have a long life in the natural atmospheres usually developed in heating chambers and in hydrogen atmospheres. In case sulphur is present in the atmosphere of the heating chamber the nickel in the alloy reacts with the sulphur to form nickel sulphide. The source of sulphur in such cases is generally the refractory lining of the heating chamber. In a carbon monoxide atmosphere the nickel in the nickel-chromium alloy reacts with carbon monoxide to form nickel carbonyl.

Steel resistors in a hydrogen atmosphere are decarburized; and this reduces the resistance of the circuit of carbon steel resistors (see Fig. 118). If the steel contains such elements as chromium and tungsten, the decarburizing action results in an increase in the resistivity of the resistor metal. Usually in neither case is this change in resistance of importance. Iron or steel resistors cannot be used in an artificial atmosphere of steam as the oxygen present, either from the air, or by dissociation of the water vapor, attacks the iron.

In all cases, whatever may be the material of the resistors, artificial atmospheres which by dissociation yield carbon may cause trouble by deposition of carbon on the windings and supports.

For a given temperature and a given resistor shape-factor, the thermal conductivity of the atmosphere of the heating chamber determines the value of the natural convection component of the flow of heat from the resistor surfaces. The thermal conductivities of most of the gases used for artificial atmospheres do not vary widely from that of air so that a correction of values, as from Fig. 134, for gases other than air is not usually necessary. The exception is hydrogen, which at furnace temperatures has a thermal conductivity of from six to seven times that of air. In the case of a hydrogen atmosphere the thermal conductivity of the film of gas adjacent to the resistor surface is so high that instead of natural convection as in air we have heat conduction through the body of the gas, a component of the total heat flow materially greater than the natural convection component under the same conditions in air. Thus with a hydrogen atmosphere the watts per square inch of resistor surface are higher than the value of air (and other gases) and we have correspondingly faster heating of the charge. This feature is not usually of sufficient importance to warrant the use of hydrogen for that purpose alone.

(To be continued)

Colored Luminous Steam

By L. C. PORTER, G. F. PRIDEAUX, and W. H. STEIGER
Engineering Dept., Edison Lamp Works, General Electric Company

SEARCHLIGHT beams swinging across the sky have been used for several years for advertising purposes. Before the advent of the night air-mail, such beacons were sufficiently unusual to accomplish their purpose. Now, however, air-mail beacons are so numerous that a searchlight beam loses its individuality and is not particuarly valuable as an advertisement. For that reason, and to avoid confusing night fliers, and also because of the necessity for complying with the regulations of the Department of Commerce regarding the installation of searchlights for advertising purposes, it has become desirable to use some other novel form of lighting.

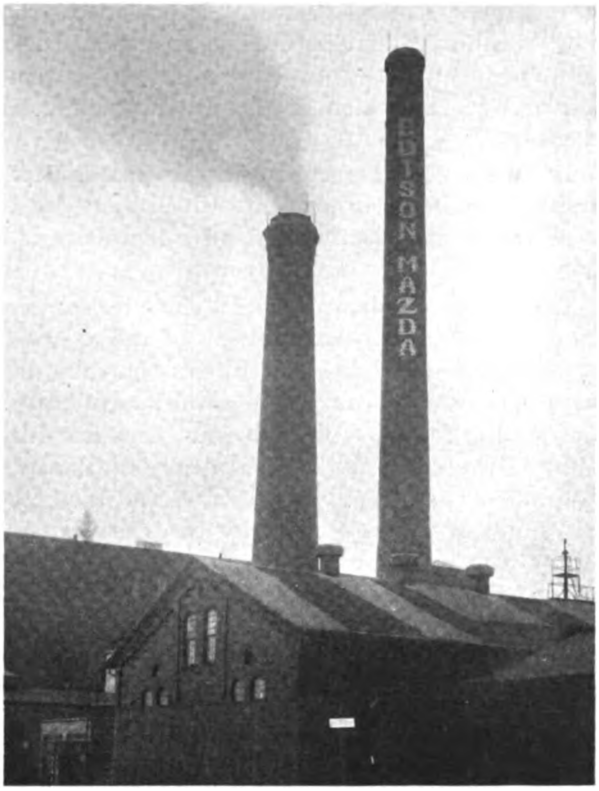

Fig. 1. Day View of the Colored Luminous Steam Beacon. The steam issuing from the stack was illuminated after dark by three groups of projectors, two of which are located just inside the wire-mesh fence that is at the lower left

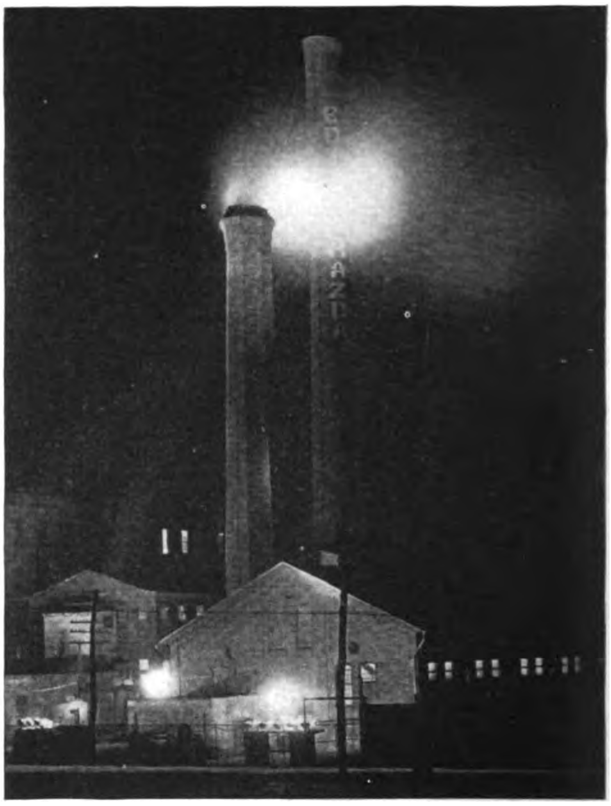

Fig. 2. A Night View of the Beacon. The photographic limitations of monochrome reproduction, the time exposure, and the constant movement of the subject together with its large areas of delicate transparency make impossible the taking of a photograph that reveals the true grandeur of the steam cloud

Steam has been used very effectively on various occasions. It was used at the Hudson-Fulton celebration and again at the Panama-Pacific Exposition. Special figures were produced by erecting steam pipes having holes drilled along their length and then playing powerful searchlight beams into the escaping steam. These installations used high-pressure steam for short periods of time.

Some years ago a lighted steam curtain 150 ft. long and 40 ft. high was employed at a historical pageant in Lexington (Mass.). Colored lights were played on the steam during the change of scenes and the combination not only prevented the audience from seeing the scenery shifted but also provided a very beautiful spectacle during these intervals.

Last Christmas the principal feature of decorative lighting at the Edison Lamp Works at Harrison, (N. J.) was a new type of steam beacon that was operated for 20 days. This beacon was the first to use low-pressure steam uncontrolled as to shape, and so attractive did it prove that passengers on evening trains running nearby invariably crowded over to that side of the coaches for a better view.

Because of its availability to the purpose, a disused stack 125 ft. high was pressed into service as a large orifice through which to discharge the low-pressure steam into the air, as shown in Fig. 1. The necessary amount of steam was supplied by the factory boilers through a three-inch pipe leading into the base of the stack and there turned upward. Initially, there was considerable speculation as to how much condensation would take place inside the cold stack. Experience showed, however, that whatever water may have condensed was carried up the stack by the steam, for not a drop reached the base of the stack.

Tests were made with various amounts of live steam from 100 to 500 hp. The former proved to be too little to make as big a display as desired; the latter made such a roar as it came out of the top of the stack that it could be heard for a radius of half a mile. In fact, the noise was greater at some distance from the stack than close to it. The roar probably originated at the outlet of the three-inch pipe and not at the seven-foot opening at the top of the stack, and doubtless could have been eliminated by a larger outlet or multiple outlets. Since the installation was to be but a temporary one, it was decided to forego the making of structural changes to avoid creating objectionable noise and to arrive at the same result by reducing the amount of steam exhausted. Three hundred horsepower of steam was found would meet these requirements and at the same time furnish a gorgeous plume.

On still nights, the plume would rise 50 ft. in the air and then gradually bend over. On windy nights, (Fig. 2), it would trail off almost horizontally in a streamer about 100 ft. long, spreading out to perhaps 30 ft. wide at the end. On some occasions it would spread out almost as wide as it was long. Sometimes the steam would swirl and again it would billow and roll. At all times it was constantly changing in density, form and direction, and even in the daytime the plume was fascinating to watch.

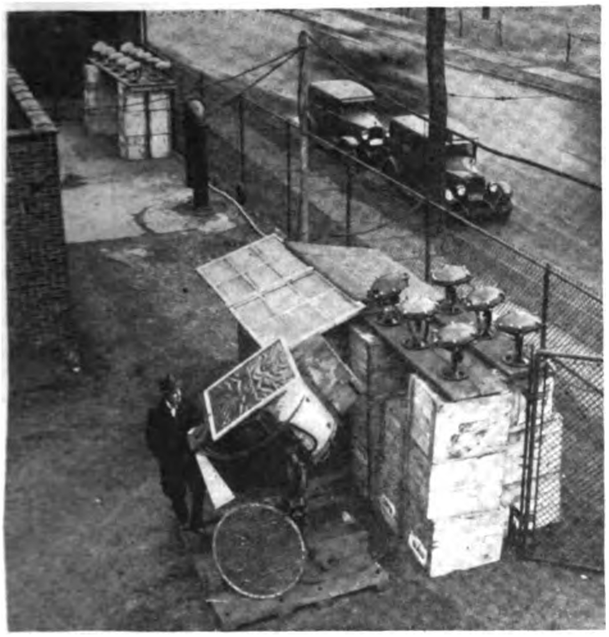

Fig. 3. In the Foreground is Shown the Control House, One Group of Floodlight Projectors, and a Searchlight. In the background is another group of projectors

On clear, cold nights the steam showed to better advantage and seemed to have more volume. The apparent volume was increased about 25 per cent by opening a draft door at the base of the stack.

To assure that the lighting would be ample, thirty 500-watt floodlight projectors (with colored cover glasses) on swivel and trunnion bases and a 36-in. 10-kw. Army type of searchlight were employed. Figs. 3 and 4 show these units in position. All these lamps were burned at about 6 per cent over voltage to add still more brilliance to the illumination.

As a final measure to assure obtaining the desired color effect, sheets of theatrical gelatin(1) were secured for use with the searchlights. Both inside and outside color screens were made. On clear nights the outside screens were used because, with their better ventilation, they operated cooler and did not fade so rapidly. The inside screens were employed on rainy nights, since the gelatin is soluble in water. Fig. 3 shows an outside screen in place on the searchlight, and an inside screen standing at the base of the light. Double sheets of gelatin, held between two pieces of one-inch mesh chicken wire, guarded against the passage of clear light in case one sheet became cracked or torn. The double thickness of course cut down the amount of transmitted light but it intensified the color and made possible the use of each screen for about a week.

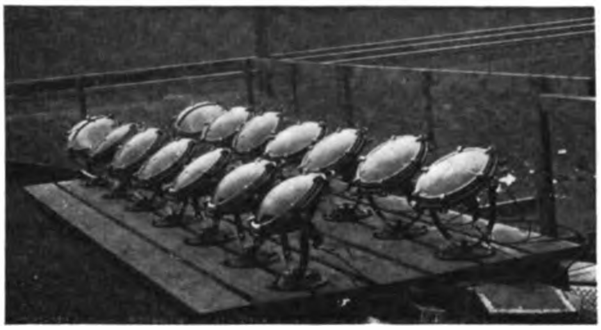

Fig. 4. The Projectors Shown in Fig. 3 Together with This Third Group Comprised the Lighting Equipment for the Beacon

The colors selected were the primary red, blue, and green, supplemented by a little amber. It was found best to use the amber at the extreme end of the steam and to keep it well away from the other colors as it was relatively so powerful as to tend to wash out the other colors.

In some preliminary tests, conducted about a year ago, it was found that a searchlight beam would not readily penetrate a cloud of steam. For this reason, all the locations for the projectors were chosen on the side toward which it was desired to have the beacon displayed to best advantage.

As a matter of convenience, one group of projectors was located on the roof of a small building and the remaining two groups were mounted on planks placed on top of the packing cases in which the projectors were shipped, Figs 3 and 4. The latter arrangement was merely a temporary expedient to allow the beams to clear the roof of a nearby building when the steam was blowing off horizontally to the north. Initially, there were 14 green projectors in Group I, 10 red projectors in Group II, and 6 amber projectors and the searchlight with a blue color screen in Group III. It was soon found, however, that better results were obtained by mixing the colors. In the eventual set-up there were in the first group 6 green, 6 red, and 2 blue projectors; in the second group 4 red, 4 green, and 2 blue; and in the third group 4 amber, 1 red, and 1 green projectors with the searchlight variedly red, blue, and green.

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(1)Charles Products Co., 276 Pearl St., New York City. The No. 75 red, No. 35 blue, and No. 37 green were selected as being the most suitable for the purpose.

Each projector was wired to a switch in the control house, Figs. 4 and 5, which was a small contractors' shanty having a section of its roof replaced by a glass window to enable the operator to watch the formations of the steam and the lighting effects. By observation from this vantage point each projector could be focused and trained individually, for the best composite effect; and the centralized control made possible the dimming of any or all the colors or the switching out of service any of the projectors that temporarily were not wanted. In fact, the operator could stand at the control board and play the colors on the steam practically as one would play music on a piano. Experience, however, showed that the steam itself produced more varied and more beautiful changes than any that could be obtained by control from the board.

Many different color settings were tried, the principal ones being shown in Fig. 6.

In general, it can be said that the most spectacular display was with the steam all red. Proportionately this is obtained with the lowest wattage, except amber. When used alone, however, the amber gave the steam a dirty appearance. Used with other colors, and particularly out at the end of the plume where little puffs of steam turned in and out of the beam, the effect was one of masses of fairy gold floating in the sky. All green on the steam was very pretty; and all blue was delicate but would require an enormous consumption of electric power to make a good showing.

Probably the most beautiful of the color combinations was obtained with the pattern shown in Fig. 6(d), particularly when viewed from a position toward which the steam was moving. In this location, one color was seen through another and numberless combinations and delicate shadings resulted. The effect was fascinating and people would stand and watch constantly changing effects. All the beautiful effects obtained in theatre lighting, by means of complicated dimmers, motor-controlled switches, etc., were presented in the lighted steam without throwing a single switch, the ever-changing variations being produced automatically by the natural changes in steam volume and density.

Perhaps the most effective color setting, combining the spectacular with the beautiful, was that obtained with the pattern illustrated in Fig. 6(h).

In all the settings of the color areas on the steam, it was found that considerable separation was required. There was of course a natural tendency to overlap them, but to do so resulted in partially washing out or flattening the individual colors.

The experience gained with this particular beacon led to the following conclusions which would improve any like installation in the future.

Four groups of projectors should be employed and located approximately 90 deg. apart on a radius of about 50 ft. from the base of the stack. Each group should consist of 1 amber, 2 red, 3 green, and 4 blue floodlight projectors each equipped with a 500-watt floodlight lamp. The lamps should be burned at normal voltage to obtain longer life. A 36-in. searchlight could be used to advantage to supplement any desired color, although it is not essential. Swivel and trunnion bases should be used on the floodlight projectors and they should be connected by flexible leads, for they will have to be trained in various directions every night depending upon the wind. Since the wind does not ordinarily change direction appreciably after dusk, one setting of the projectors at that time will usually hold until midnight, after which there is little advantage in operating such a beacon.

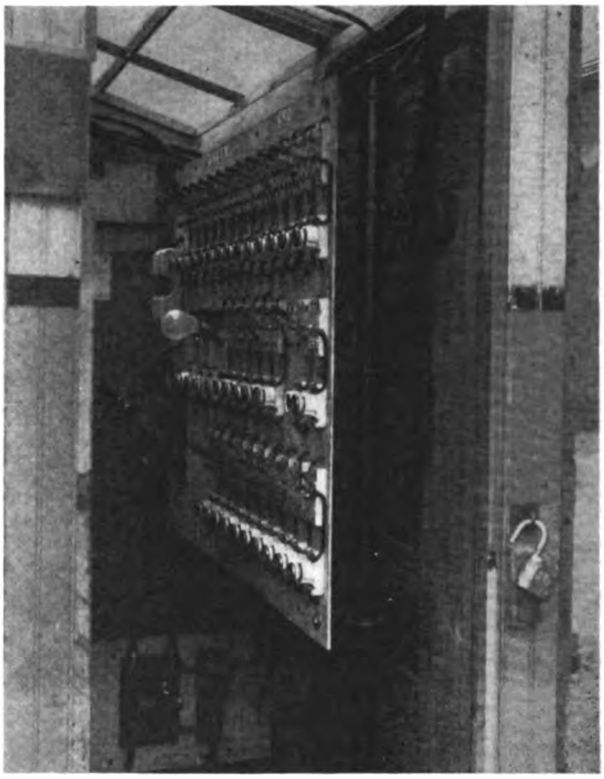

Fig. 5. Control-house Switchboard for Manipulating the Color Effects on the Steam Cloud

If there are any neighboring obstructions such as chimneys, buildings, etc., care should be taken to mount the projectors above them, or at least to study the prevailing wind direction and then locate the floodlights so as to reach the steam with as little interference as possible.

Probably individual switches for each projector are not necessary, although convenient for operation. Each color in each group, however, should have a separate switch to enable the use of the colors separately or together.

The cost of such an installation is not high and compares very favorably with any ordinary floodlighting installation. The principal items of cost are the projectors and the labor of installation. Maintenance is made up largely of the cost of the steam. In certain cases, exhaust steam can be utilized without expense. The remaining cost is that of the current and lamps, and a half-hour's labor each night to direct the beams of the projectors.

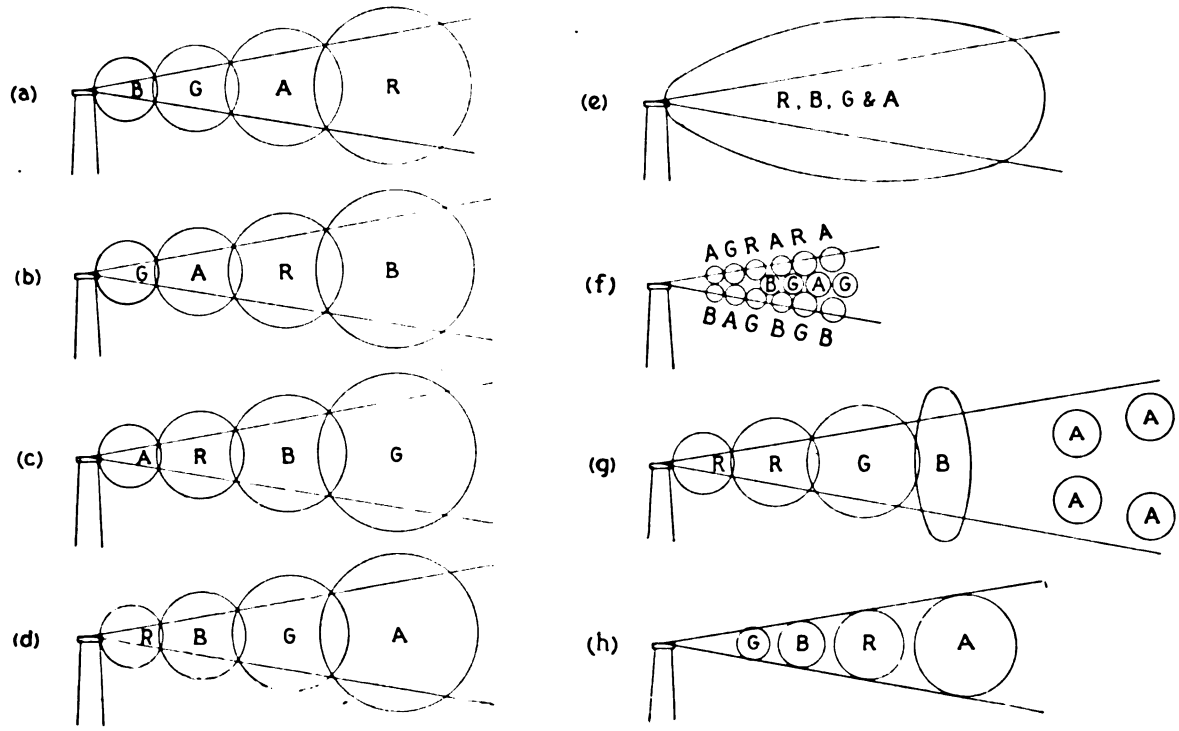

Fig. 6. Diagrams of the Various Arrangements Employed in the Layout of the Colors
A: Amber *B:* Blue *G:* Green *R:* Red

In any industrial town there are many jets of escaping steam varying all the way from a few feet to perhaps more than a 100 ft. high. (The writer is now laying out the equipment for lighting such a jet that rises 400 ft. into the air.) Many of these offer an opportunity to produce a beautiful display at a relatively low cost. The small ones can be floodlighted by wide-spread beams that, with one setting, will cover the steam no matter what the direction of the wind. To accomplish this in the case of large steam columns, however, would require an area of illumination which in cost would far exceed that of labor in having the beams directed each night. Roughly, ten watts per square foot of projected area of steam will furnish adequate brilliance of color for red or green.

If desired, it is entirely practical to project advertising matter onto a steam column. A 1000-watt Mazda lamp in an ordinary stereopticon will produce words several feet high. For larger steam jets, a special and more powerful type of projector should be used. In making lantern slides for the projector, the letters should be transparent and the background opaque—the reverse of the ordinary lantern slide. The projectors should be pointed in approximately the direction from which the legend is to be read.

There is, then, in this development an excellent opportunity to present a new, novel, and truly beautiful form of advertising that will secure most favorable comment from all who see it.

Vacuum Tubes as Oscillation Generators

PART VIII

A HIGH-EFFICIENCY CIRCUIT WITH SQUARE CURRENT WAVES (Cont'd)

By D. C. PRINCE and F. B. VOGDES
Research Laboratory, General Electric Company

THE terminal conditions of the plate and grid coils are known; and if the coefficient of coupling be assumed, it will be found that all voltages and currents throughout this part of the circuit may be readily calculated. Since the maximum possible coefficient of coupling of such a transformer can be estimated, after a little experience, from its volt-ampere and voltage ratings with a fair degree of accuracy for a given type of construction, this is the logical factor to use as a basis of calculation. A high coefficient of coupling is desirable, as it makes for easy energy interchange between the circuits and prevents any appreciable phase differences. (This point is more fully covered in another section.) A very high coefficient of coupling, however, is obtained only at the expense of the insulation between coils. In general, it is usually found that a coefficient of coupling between 0.35 and 0.50 will give satisfactory results.

Calculation of Coupling Between Plate and Grid Circuits

Proceeding to the method of calculation, let

$$\left.\begin{array}{ll} P_1 = I_1^2\omega L_1 & \text{be the wattless power in the primary, due to its own current and inductance.} \\ P_2 = I_2^2\omega L_2 & \text{be the wattless power in the secondary, due to its own current and inductance.} \\ P_c = I_1 I_2 \omega M_o & \text{be the wattless power which is held between the two circuits.} \\ Q_1 = I_1^2/\omega C_1 & \text{be the total primary volt-amperes.} \\ Q_2 = I_2^2/\omega C_2 & \text{be the total secondary volt-amperes.} \end{array}\right\} \quad (4)$$

Since the only real power transferred through the coupling is that utilized in the grids, an amount very small in comparison with the wattless volt-amperes involved, and since the coefficient of coupling is high, the primary and secondary currents may be assumed to be in phase in calculating their magnitudes, which will put the primary and secondary voltages in phase also.

In order that the phase relationships may be described definitely, Fig. 70 will be used as a basis for reference. Current enters the two coils at a_1 and a_2 in the same phase; let it be assumed that at some instant the current in L_1 is developing its maximum effort to make a_1 positive with respect to b_1. At the same instant, let the current in L_2 also be exerting its maximum effort to the same end. Then both currents at the same instant are also exerting their peak effort to make a_2 positive with respect to b_2.

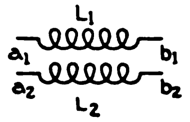

Fig. 70. Diagram of Symbols Used in Describing Phase Relationships in Coupled Circuits

Let these be the conditions assumed for positive values of P_1, P_2, and P_c.

Then

$$P_1 + P_c = Q_1 \tag{5}$$

$$P_2 + P_c = Q_2 \tag{6}$$

and

$$P_1 P_2 = \frac{P_c^2}{K^2} \tag{7}$$

where K is the coefficient of coupling.[10]

The elimination of P_1 and P_2 by successive multiplications and substitutions of Equations (5), (6), and (7) and the subsequent solution of the resulting quadratic gives

$$P_c = \frac{-(Q_1+Q_2) \pm \sqrt{(Q_1+Q_2)^2 + 4Q_1Q_2\left(\frac{1}{K^2}-1\right)}}{2\left(\frac{1}{K^2}-1\right)}. \tag{8}$$

---

[10] Equation (7) follows from the definition of the coefficient of coupling as follows:

$$M_o = K\sqrt{L_1 L_2} \text{ by definition.}$$

Multiplying by the factor $I_1 I_2 \omega$ gives

$$I_1 I_2 \omega M_o = K\sqrt{I_1^2\omega L_1 \cdot I_2^2 \omega L_2}$$

Substituting from Equation (4)

$$P_c = K\sqrt{P_1 P_2} \quad \text{or} \quad P_1 P_2 = \frac{P_c^2}{K^2}$$

References made to material hitherto published in this series of articles may readily be located from the following table:

Part	*Issue*	*Figs.*	*Equations*	*Tables*	*Footnotes*
Part I	June, 1927, p. 320	1 to 4	—	—	—
Part II	Oct., 1927, p. 501	5 to 21	—	I to III	(1) to (4)
Part III	Feb., 1928, p. 97	22 to 23	—	IV	—
Part IV	Mar., 1928, p. 147	24 to 34	—	—	—
Part V	July, 1928, p. 388	35 to 43	—	—	(5) to (7)
Part VI	Oct., 1928, p. 546	44 to 60	—	—	(8)
Part VII	Dec., 1928, p. 678	61 to 69	(1) to (3)	—	(9)

Inspection of the original equations shows that P_1 and P_2 may now be readily determined, thus giving the values of L_1, L_2, and M_0. As the values of C_1 and C_2 (primary and secondary capacities) and r_g are easily derived from the assumed voltages and distribution of the stored energy as already shown, there remain only the load resistance, pass condenser for r_g, and inductances in the harmonic transformer to be determined.

If the circuit is loaded, as shown in Fig. 71, it is only necessary in calculating r_L to pick a resistance which will absorb the output power at the known current I_1.

The function of C_p is to pass the small amount of alternating current which gets through the harmonic transformer so that it does not have to go through r_g. The corresponding current which flows to the power supply through L_3 will undoubtedly be short-circuited in this manner and it is desirable to have both paths of the same nature. The value of C_p is not critical; it must merely present a relatively low impedance to a double-frequency current of magnitude equal to a fraction of the grid current. The function of r_p in series with it is to discourage parasitic oscillations; its value is best found by trial.

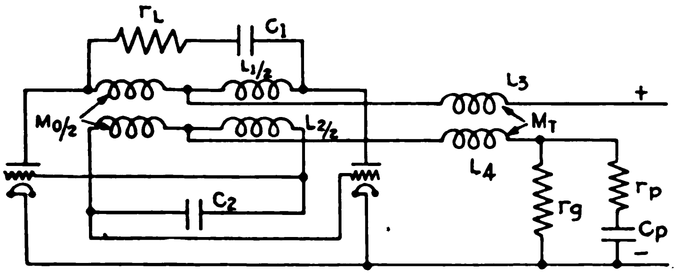

Fig. 71. Diagram of High-efficiency Circuit Showing Nomenclature

The Harmonic Transformer

The function of the harmonic transformer is to pass the steady direct currents from the power source and grid-leak resistance and to hold up the double frequency and its harmonic voltages, which always appear wherever rectification takes place. Now, it is impossible to do this without drawing some exciting current; and it will be found that this exciting current must be quite large if bad internal tuning effects are to be avoided. It has already been shown that if separate chokes are used in the two circuits the plate ripple will be increasing the plate current while the grid ripple is decreasing the grid current. This is a condition giving bad additional losses in the tubes which could be reduced almost to zero if the two currents rose and fell together. The latter state may be obtained by coupling the two chokes together into a transformer and making the plate-current ripple drive the grid-current ripple in the right phase relation.

Before proceeding further, it is well to see what the magnitudes of the voltages are which it is proposed to hold back. The fundamental component of the ripple (*i.e.*, the double-output-frequency component) for double-wave rectifiers is $\frac{2}{3\pi}$ times the voltage across the outer terminals of the alternating current winding. Hence, neglecting all other components, and designating by E_3 and E_4 the voltages across L_3 and L_4 (Fig. 71)

$$E_3 = \frac{2}{3\pi} E_1 \quad \text{and} \quad E_4 = \frac{2}{3\pi} E_2 \tag{9}$$

As a further approximation assume that all the impedance presented to these voltages is that located in the harmonic transformer. The ripple currents will be taken as a certain percentage of the direct currents. Their relative magnitude will depend on the particular circuit used; but some circuits, because of relatively high direct currents and low voltages, can be run with smaller ripples than others. The limit which occurs is due to internal resonance of the coils.

The conditions to be met by the harmonic transformer are now apparent. The solution of the problem is the same as for the transformer in the oscillating circuit. Upon examination of the relative polarities of the voltages and currents, however, it is discovered that if the previous nomenclature is held to, the actual numerical value of the voltage applied to L_4 will be negative whereas, before, everything had a positive numerical value. This has an important practical bearing on the problem, as it puts a limit on the coefficient of coupling.

Let X_3 = reactance of coil L_3

X_4 = reactance of coil L_4

X_M = mutual reactance

I_3 = alternating current through L_3

I_4 = alternating current through L

Then

$$I_3X_3 + I_4X_M = E_3 \tag{10}$$

$$I_4X_4 + I_3X_M = E_4 \tag{11}$$

$$X_3X_4 = \frac{X_M^2}{K^2} \tag{12}$$

The solution of these equations is accomplished by a method similar to that applied to Equations (5), (6), and (7) and gives

$$X_M = \frac{-(E_3I_3 + E_4I_4) \pm \sqrt{(E_3I_3 + E_4I_4)^2 + 4E_3E_4I_3I_4\left(\frac{I}{K^2} - 1\right)}}{2\,I_3I_4\left(\frac{1}{K^2} - 1\right)} \tag{13}$$

The negative value of E_4 makes possible an imaginary value for X_M which is, of course, unobtainable in practice. In order to avoid this, it will be found that K must exceed a certain value given by

$$K^2 > \frac{-4\,E_3E_4I_3I_4}{(E_3I_3-E_4I_4)^2} \tag{14}$$

If it is impossible or impractical to build a set of coils meeting this requirement, it will be necessary to give new values to some of the assumed constants on which the circuit has been calculated. Changing the assumed ripples in the plate and grid currents will change only the actual values of X_3, X_4, and X_M, leaving their relative values unchanged. This is not likely to give any relief in the situation; and earlier assumptions must be scrutinized. Of these, the only ones which can be changed to advantage are those affecting the voltage in the grid circuit; for if this can be lowered the requirements imposed on the harmonic transformer will be easier to meet, as will be seen by examination of Equation (14). As soon as a practical value of K is determined, the values of X_M, X_3, and X_4 follow from Equations (13), (10), and (11), taking them in the order named.

Commutation of Grid Currents

Among the assumptions which were made earlier in this chapter was one to the effect that transfer of grid currents would be accomplished as though this transfer had no effect on the voltage which would otherwise exist in the secondary circuit. In examining the truth of this assumption, it is not practical to go very far into the investigation; so it will merely be assumed that during a short period of commutation the current in the secondary coil remains constant, which will be very nearly the case, and the first assumption verified on this basis. Let

i_o = maximum of current flowing through inductance L_2, and assume a constant current of this value to flow through L_2 during commutation. (This is additional to the direct components of the grid currents)
i_1 = current in grid from which current is being transferred
i_2 = current in grid to which current is being transferred
i_g = steady value of grid current during the active part of the cycle. (This assumes complete smoothing by the harmonic transformer.)
r = resistance of two grids in series.

Then it can be shown that

$$i_2 = i_o\left(1-\epsilon^{-\frac{t}{rC_2}}\right)+\frac{i_g}{2}\left(1-\epsilon^{-\frac{t}{rC_2}}\right)=\left(i_o+\frac{i_g}{2}\right)\left(1-\epsilon^{-\frac{t}{rC_2}}\right) \tag{15}$$

and

$$i_1 = -i_o\left(1-\epsilon^{-\frac{t}{rC_2}}\right)+\frac{i_g}{2}\left(1+\epsilon^{-\frac{t}{rC_2}}\right) \tag{16}$$

By setting i_2 equal to i_g it is possible to calculate the time at which transfer is completed, and in the usual case no appreciable difference is shown between this value and that given by the first assumption.

Losses in Tubes During Commutation

The loss in the plate circuit during commutation may be unduly increased by using too large a lap angle. This is a matter which probably cannot be calculated accurately, because of the lack of exact knowledge of many things which happen in an extremely short interval of time; but if certain reasonable assumptions are made, at least the order of magnitude of the additional losses may be estimated.

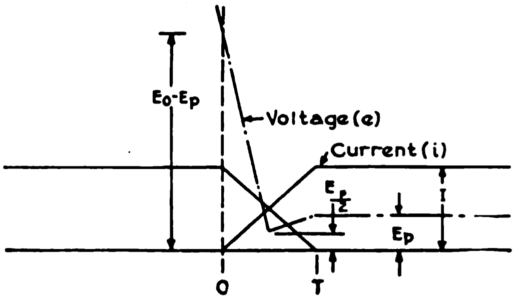

Fig. 72. Assumed Plate Potential During Period of Commutation

First let it be assumed that there is no phase displacement between the grid excitation and the plate voltage, under which condition commutation is effected by the grids. Then at the start and finish of the period of commutation, the tube which is carrying the load current should have across it only the voltage drop actually required to pass the current. The other tube will have the remainder of the voltage of the primary circuit impressed upon it. While it is extremely difficult to say exactly how the voltage will divide between the tubes during commutation, a likely division will be of the nature shown in Fig. 72. Let

E_o = the voltage in the primary circuit at either end of the period of commutation
E_p = the steady plate drop while either tube is carrying all the load current
e = the instantaneous voltage across the tube into which the current is being commutated
i = the instantaneous current through the same tube.

Then assume that

$$i = \frac{I}{T}t$$

$$e = (E_o-E_p)-\frac{2\left(E_o-\frac{3}{2}E_p\right)}{T}t \text{ for } 0 < t < \frac{T}{2}$$

and

$$e = \frac{E_p}{T}t \text{ for } \frac{T}{2} < t < T$$

Measuring t in degrees and calling the losses in both tubes W_1,

$$W_1 = \frac{4}{360}\left\{\frac{(E_o - E_p)\,I}{T}\int_o^{\frac{T}{2}} t\,dt - \frac{2\,(E_o - \frac{3}{2}\,E_p)\,I}{T^2}\int_o^{\frac{T}{2}} t^2\,dt + \frac{I\,E_p}{T^2}\int_{\frac{T}{2}}^{T} t^2\,dt\right\}$$

$$= \frac{I\,T}{2160}\left\{E_o + 7\,E_p\right\}$$

Now let W_2 = watts lost in one tube during time $2\,T$ if it carried the steady current I. Then

$$W_2 = \frac{2\,T}{360} \times I \times E_p$$

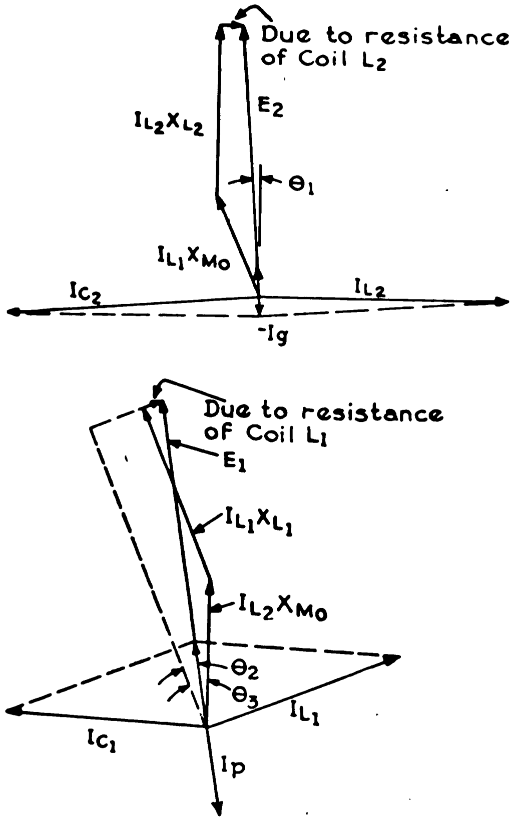

Fig. 73. Vector Diagram of High-efficiency Circuit

When $W_1 = W_2$ there are no additional losses due to commutation, and

$$\frac{2\,E_p}{360} = \frac{E_o + 7\,E_p}{2160}$$

or

$$E_o = 5\,E_p$$

and if $E_o < 5\,E_p$ it is unlikely that there will be any serious losses due to the commutation even though the assumptions may not be substantiated in practice.

Vector Diagram of Circuit

Up to this point the phase displacement between the grid excitation and plate voltage has been assumed to be zero. While it is usually very small it is often desirable to know its value. This can be determined by referring to Fig. 73. The subscripts refer to the different parts of the circuit shown in Fig. 71. The root-mean-square components of plate and grid currents are designated I_p and I_g respectively.

Starting with i_{L_2} it is found that E_2 leads it by 90° + θ_1 in order that this coil may be a source of power for the secondary. I_{C_2} leads E_2 by 90° and I_g must have such a value that the vector sum of I_{L_2}, I_{C_2}, and I_g is zero. E_2 consists of the voltage induced in L_2 by its own current $(I_{L_2}\,X_{L_2})$, the voltage induced in L_2 by the primary current $(I_{L_1}\,X_{M_o})$, and the resistance drop in L_2.

In the primary circuit there is its own current I_{L_1} and the voltage induced in the primary coil by the secondary current $(I_{L_2}\,X_{M_o})$. Adding to the latter the voltage induced in the primary coil by its own current $(I_{L_1}\;X_{L_1})$ and the resistance drop in the same coil gives E_1, the primary voltage. I_p must then be 180° out of phase with E_1 in order to represent input to the circuit, and I_{C_1} must combine with I_{L_1} and I_p to give a vector sum of zero. Let

Q_1 = total primary reactive volt-amperes

Q_2 = total secondary reactive volt-amperes

P_c = reactive volt-amperes common to both circuits

P_g = watts lost in grids.

Then if the resistance of the coils themselves be neglected

$$\left.\begin{aligned} \theta_1 &= \tan^{-1}\frac{P_g}{Q_2} \\ \theta_2 &= \tan^{-1}\frac{P_g}{Q_1} \\ \theta_3 &= \tan^{-1}\frac{P_g}{P_c} \end{aligned}\right\} \qquad (17)$$

and the angle ϕ by which the grid excitation leads the plate voltage is given by

$$\phi = \theta_1 + \theta_2 - \theta_3 \qquad (18)$$

Production of Lead Angle

In circuits using soft tubes, *i.e.*, tubes which have control only to the extent that current flow may be held back if once stopped by external sources, it is necessary that the grid excitation shall lead the plate voltage in phase by such an amount that commutation is completed before the point of reversal of the commutating voltage is reached. This may be accomplished by placing a condenser in each plate lead bridged by a choke of high inductance to pass the direct component of plate current.

The displacement of voltages produced by such a device may be seen by referring to Fig. 74. The tubes are here represented as a source of a-c. power feeding the oscillating circuit which, being tuned, may be represented as a pure resistance. The circuit is completed by the two phasing condensers. That part consisting of the oscillating circuit and phasing condensers is so drawn that the lengths and directions of the different impedances are representative of the voltages across the parts.

The grid voltage will be practically in phase with the voltage across the oscillating circuit; and any difference may be calculated by the method just shown. Hence the difference in phase between grid excitation and plate voltage is known as soon as the impedances are known; for, if the effective resistance of the oscillating circuit is known, the size of the condensers required to produce a given phase displacement may be calculated. Since the voltage across the oscillating circuit and the power output are known, its effective resistance is readily calculated.

Example Illustrating Method of Calculation

The circuit to be calculated is to use two 50-watt tubes having thoriated filaments and is to draw 500 milliamperes from a 1000-volt d-c. source for input. The frequency is to be 12,000 cycles. Investigation of the tubes show that they will pass 500 milliamperes plate current with a plate drop of about 165 volts, a grid drop of about 125 volts, and a grid current of 85 milliamperes. This gives:

Applied voltage	(E_c) =	1000 volts
Plate drop under full-load current	(E_p) =	165 volts
Grid drop under full-load current	(E_g) =	125 volts
Input current	(I) =	500 ma.
Grid current	(i_g) =	85 ma.
Input	=	500 watts

Assuming 80 per cent efficiency, the output will be 400 watts, and as the reactive power is to be 4 π times the watts, there will be 5000 volt-amperes in both circuits.

From Equation (1), the voltage in the primary circuit (E_1) is

$$E_1=\frac{\pi}{\sqrt{2}}(E_c-E_p)$$

$$=\frac{\pi}{\sqrt{2}}(1000-165)=1850 \text{ volts (r.m.s.)}$$

Let it be assumed that an interval of 10 deg. will be sufficient time for commutation in the grid circuit. Then the r.m.s. voltage in the secondary circuit (E_2) is given by Equation (3)

$$E_2=\frac{E_g}{\sqrt{2}\sin\theta}=\frac{125}{\sqrt{2}\sin 5^\circ}=1015 \text{ volts (r.m.s.)}$$

and the voltage across the grid resistance (E_r) is given by Equation (2).

$$E_r=\frac{\sqrt{2}}{\pi}E_2-E_g$$

$$=\frac{\sqrt{2}}{\pi}\times 1015-125=333 \text{ volts.}$$

At 85 ma., this represents 28 watts loss, and the impedance of the grid resistance is

$$r_g=\frac{333}{0.085}=3920 \text{ ohms.}$$

If it is assumed that 2000 volt-amperes out of the total of 5000 will be in the secondary circuit, the losses in the secondary circuit will be

Loss in grids $2\times125\times0.085$	= 21 watts
Loss in circuit due to resistance (at 0.01 power-factor)	= 20 watts
Loss in r_g	= 28 watts
Total loss in secondary circuit	= 69 watts

This gives thirty volt-amperes in the secondary circuit for every watt lost, which appears to be a good value.

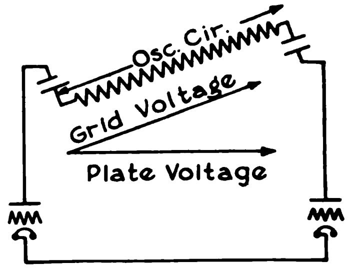

Fig. 74. Method of Producing Phase Advance for the Grid Excitation

It can now be shown that commutation will occur in substantially the 10 deg. assumed. This may be accomplished by the use of Equation (15).

$$i_o=\sqrt{2}\times\frac{2000}{E_2}=2.79 \text{ amp.}$$

$$\frac{1}{2\pi f C_2}=\frac{E_2}{I_2}=\frac{1015}{0.707\times2.79}$$

from which $C_2=2.57\times10^{-8}$ microfarad

$$r=\frac{2E_g}{I_g}=\frac{2\times125}{0.085}=2940 \text{ ohms}$$

Substituting in Equation (15) for the finish of transfer

$$i_2=\left(i_o+\frac{i_g}{2}\right)\left(1-\epsilon^{-\frac{t}{rC_1}}\right)$$

$$0.085=(2.79+0.043)\left(1-\epsilon^{-\frac{t}{rC_1}}\right)$$

from which

$$\frac{t}{rC_2}=0.0304$$

$$t=0.0304\ r\ C_2=0.0304\times2940\times2.57\times10^{-8}$$

$$=2.295\times10^{-6} \text{ sec.}$$

12,000 cycles = 4.32×10^{6} deg./sec.

Therefore, the period of transfer covers

$$2.295\times 4.32=9.9 \text{ deg.}$$

It has already been decided to divide the reactive power in the circuit so that there are 3000 volt-amperes in the primary (Q_1) and 2000 volt-amperes in the secondary (Q_2). Hence if the coefficient of coupling between primary and secondary (K) be assumed, the value of the reactive power common to both circuits (P_c) may be obtained from Equation (8).

$$P_c=\frac{-(Q_1+Q_2)\pm\sqrt{(Q_1+Q_2)^2+4Q_1Q_2\left(\frac{1}{K^2}-1\right)}}{2\left(\frac{1}{K^2}-1\right)}$$

and if $K=0.50$, then $\left(\frac{1}{K^2}-1\right)=3$, and

$$P_c=\frac{-5000\pm\sqrt{5000^2+4\times 3000\times 2000\times 3}}{2\times 3}=+808 \text{ or}$$

-2475; and the positive value is the one desired in this case.

Since the loss due to the grids (P_g) is 69 watts, the phase displacement between grid and plate voltages may be calculated by Equations (17) and (18).

$$\theta_1=\tan^{-1}\frac{P_g}{Q_2}=\tan^{-1}\frac{69}{2000}=2 \text{ deg.}$$

$$\theta_2=\tan^{-1}\frac{P_g}{Q_1}=\tan^{-1}\frac{69}{3000}=1 \text{ deg. } 20 \text{ min.}$$

$$\theta_3=\tan^{-1}\frac{P_g}{P_c}=\tan^{-1}\frac{69}{808}=4 \text{ deg. } 55 \text{ min.}$$

$$\phi=\theta_1+\theta_2-\theta_3=-(1 \text{ deg. } 35 \text{ min.})$$

Calculation of Constants of Main Oscillating Circuit

E_1, the primary voltage, has been shown to be 1850 volts r.m.s.

E_2, the secondary voltage, has been shown to be 1015 volts r.m.s. Since there are 3000 volt-amperes in the primary, the current is

$$I_1=\frac{3000}{E_1}=\frac{3000}{1850}=1.622 \text{ amp. (r.m.s.)}$$

and since there are 2000 volt-amperes in the secondary, the current here is

$$I_2=\frac{2000}{E_2}=\frac{2000}{1015}=1.97 \text{ amp. (r.m.s.)}$$

There are 808 volt-amperes common to both circuits or

$$\omega M_o I_1 I_2=808$$

$\omega=75{,}400$ for 12,000 cycles, hence

$$\omega M_o=\frac{808}{1.622\times 1.97}=253 \text{ ohms}$$

$$M_o=\frac{253}{75{,}400}=3.36 \text{ millihenrys.}$$

The volt-amperes in the primary coil due to its self inductance are

$$\omega L_1 I_1^2=3000-808=2192$$

$$\omega L_1=\frac{2192}{(1.622)^2}=833 \text{ ohms.}$$

$$L_1=\frac{833}{75{,}400}=11.04 \text{ millihenrys.}$$

The volt-amperes in the secondary coil due to its self-inductance are

$$\omega L_2 I_2^2=2000-808=1192$$

$$\omega L_2=\frac{1192}{(1.97)^2}=307 \text{ ohms}$$

$$L_2=\frac{307}{75{,}400}=4.08 \text{ millihenrys.}$$

The volt-amperes in the primary capacity are

$$\frac{I_1^2}{\omega C_1}=3000$$

$$\frac{1}{\omega C_1}=\frac{3000}{(1.622)^2}=1.140 \text{ ohms.}$$

$$C_1=0.01163 \text{ microfarad.}$$

The volt-amperes in the secondary capacity are

$$\frac{I_2^2}{\omega C_2}=2000$$

$$\frac{1}{\omega C_2}=\frac{2000}{(1.97)^2}=516 \text{ ohms.}$$

$$C_2=0.0257 \text{ microfarard.}$$

The voltages across the harmonic transformer are given by Equations (9).

$$E_3=\frac{2}{3\pi}E_1=\frac{2}{3\pi}\times 1850=394 \text{ volts (r.m.s.)}$$
$$=557 \text{ volts (peak)}$$

$$E_4=\frac{2}{3\pi}E_2=\frac{2}{3\pi}\times 1015=215 \text{ volts (r.m.s.)}$$
$$=306 \text{ volts (peak)}$$

and the latter will be negative in sign under the assumed system of nomenclature.

Let it be assumed that these voltages cause ripple currents (I_3 and I_4) to flow which have peaks equal to 20 per cent of the direct currents. Hence,

$$I_3=0.2\,I=0.2\times 0.5=0.1 \text{ amp. (peak)}$$
$$=0.0707 \text{ amp. (r.m.s.)}$$
$$I_4=0.2\,i_g=0.2\times 0.085=0.017 \text{ amp. (peak)}$$
$$=0.012 \text{ amp. (r.m.s.)}$$

Using Equation (14) to find the minimum possible coupling gives

$$K^2 > \frac{-4}{\frac{E_3I_3}{E_4I_4}+\frac{E_4I_4}{E_3I_3}-2}$$

$$K^2 > \frac{-4}{-\frac{394\times 0.0707}{215\times 0.012}-\frac{215\times 0.012}{394\times 0.0707}-2}$$

$$K^2 > 0.313.$$

This gives a value of 0.56 as the minimum for K, and substituting this value in Equation (13) gives

$$X_M = \frac{-(E_3I_3+E_4I_4) \pm \sqrt{(E_3I_3+E_4I_4)^2+4\,E_3E_4I_3I_4\left(\frac{1}{K^2}-1\right)}}{2\,I_3I_4\left(\frac{1}{K^2}-1\right)}$$

$$= \frac{-(394\times 0.0707 - 215\times 0.012)\pm 0}{2\times 0.0707\times 0.012\times(3.19-1)} = -6780 \text{ ohms.}$$

Knowing X_M, the values of X_3 and X_4, the reactances of coils L_3 and L_4 are obtained from Equations (10) and (11)

$$X_3 = \frac{E_3 - I_4X_M}{I_3}$$

$$= \frac{394+0.012\times 6780}{0.0707} = 6720 \text{ ohms}$$

$$X_4 = \frac{E_4 - I_3X_M}{I_4}$$

$$= \frac{-215+0.0707\times 6780}{0.012} = 21{,}900 \text{ ohms.}$$

TABLE V

12,000-CYCLE SQUARE-WAVE CIRCUIT USING TWO 50-WATT THORIATED FILAMENT TUBES

Part	Calculated Value	Actual Value	Resistance
C_1	0.01163 mfd.	0.012 mfd.	....
C_2	0.0257 mfd.	0.026 mfd.	....
C_p	....	2.0 mfd.	....
L_1	11.04 millihenrys	11.2 mh.	6 ohms
L_2	4.08 millihenrys	4.0 mh.	3.33 ohms
L_3	44.6 millihenrys	44.67 mh.	36.5 ohms
L_4	145.3 millihenrys	146.6 mh.	119 ohms
M_o	+3.36 millihenrys	+3.43 mh.	....
M_T	−45 millihenrys	−44.9 mh.	....
r_L	....	....	....
r_g	3920 ohms	4100 ohms	....
r_p	....	500 ohms	....

At 24,000 cycles (150,800 radians/sec.) these impedances give

$$M_T = -45 \text{ millihenrys}$$
$$L_3 = 44.6 \text{ millihenrys}$$
$$L_4 = 145.3 \text{ millihenrys}$$

Actual Performance of Small Circuit

In order to show the probable variations between actual performance and performance as calculated, the circuit which has just been analyzed was set up in the laboratory. The tubes had been selected and tested before the calculations were started, and the actual and calculated values of the other parts of the circuit are as shown in Table V.

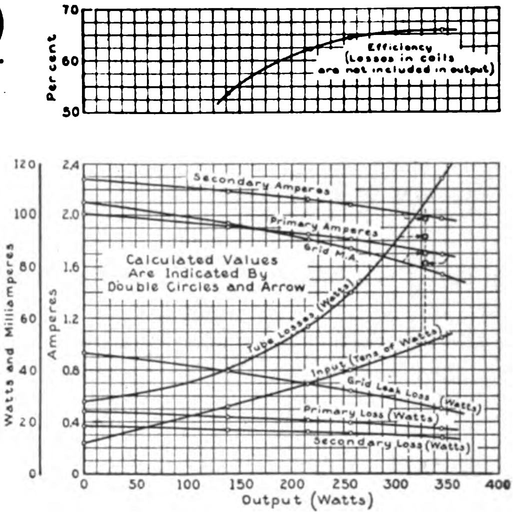

Fig. 75. Typical Performance Curves of a Two-tube High-efficiency Circuit

The harmonic transformer tuned with its internal capacity plus the capacity between the primary and secondary coils of the oscillating circuit at about 78,000 cycles.

The performance of the circuit is shown in Fig. 75. The output as measured along the axis of abscissas is the actual useful output in the resistance r_L. The calculations were based on 500 watts input, and, from the test curves, this corresponds to 329 watts output. Drawing a vertical line through this value, and inserting on it the calculated values for the different currents and the tube losses, shows that the performance is practically as calculated.

(*Concluded*)

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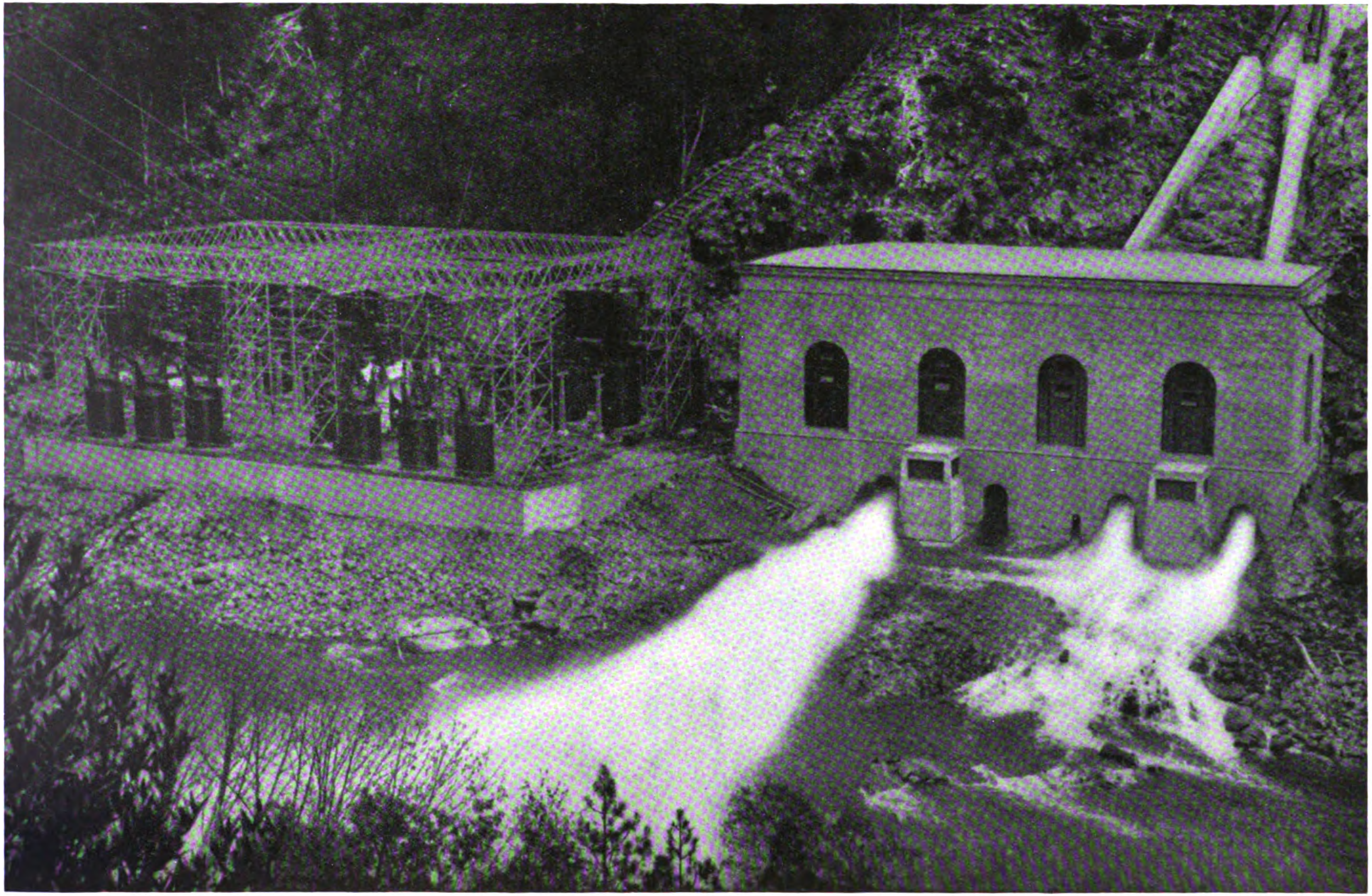

THE HIGHEST HEAD PLANT IN AMERICA

The Buck's Creek Station of the Great Western Power Company, containing two 25,000-kv-a. hydroelectric units operating under 2562 ft. head and generating at 11,000 volts. In the outdoor yard at the left, the output of the generating plant is stepped up to 240,000 volts for transmission

GENERAL ELECTRIC REVIEW

Vol. 32 June, 1929 No. 6

PROGRESS IN POWER SYSTEM DEVELOPMENT

The past decade in the history of the central-station industry is one of marked achievement in the various branches of its widespread activities.

New principles have been applied and extended in all directions with beneficial results to the industry and indeed to every individual whether connected with it or not, so broad are the effects of improvements in the production and marketing of energy in its most mobile form.

Specifically, tremendous strides have been taken in linking up the great power systems of the country.

Operators have been quick to sense the distinct advantages of interconnection, particularly the greater operating capacity for the same investment. Larger units can also be utilized to advantage, with substantial savings in investment cost per kilowatt. It is also found that economies can be effected in operating costs, for plants can be run at higher overall efficiency when interconnected. Another factor is the increased reliability resulting from flexibility and through diversification of the risk of breakdown.

Coördinated effort on the part of public-utility executives and engineers, as reflected in the work of the National Electric Light Association, has been an outstanding factor in facilitating these great accomplishments. There has been achieved for the industry a degree of simplified practice which has enabled interconnection to be furthered, both in its engineering and commercial aspects, with a minimum of trouble and expense. Supplementing this constructive activity of the N.E.L.A., the energetic research and development policies of apparatus manufacturers have enabled them to place in the hands of the utilities, without delay, the tools with which to forge these important links.

The rapidly changing character of the large apparatus now being built reflects the influence of the new era of interconnected system operation. The addition of load-ratio control to power transformers dates back only a few years, yet last year this invaluable aid to interconnection was applied to 1,250,000 kv-a. of the large transformers built by one company alone, and the application is steadily increasing.

In steam-turbine-generator construction, the insistent demand for units of greater and still greater capacities has been anticipated and met at every stage of a particularly rapid advance in unit output. It is an astonishing fact that generating units such as the 165,000-kw. machine at Philo and the 208,000-kw. 22,000-volt unit at State Line can be constructed, erected, and put into service without causing a ripple of excitement. The 160,000-kw. double-winding turbine-generator unit now successfully undergoing test at the factory and destined for the East River Station of the New York Edison Co. is doubly interesting because it is not only much greater in output than any previous single generator but because it introduces a new and far-reaching principle into generating station bus and switch structure layout and design. The double-winding principle has added flexibility to the design of the central station by utilizing the economy of very large generating units; while avoiding the attendant disadvantage of high power concentration.

Large savings in switch-house cost are being effected in the East River Station, and also in the Cahokia Station of the Union Electric Light & Power Co., by the adoption of this interesting departure from former practice.

Significant also is the celerity with which the industry has seized on the outstanding advantages of 1200-lb. steam pressure with assurance of high efficiency coupled with reasonable first cost. Arriving out of this general trend toward higher pressures has come the new type of compound-turbine-generator construction in which the high-pressure unit is mounted directly above the generator of the low-pressure unit with consequent savings in building and installation costs.

The foregoing examples of engineering achievement are cited as connoting close coöperation between the manufacturers' engineers and those of the utilities. At the present time these advances have far greater significance. They constitute an answer to the public utility executives' demand for a reduction in system cost per kilowatt.

A review of progress indicates that ways and means are being found to reduce system investment without sacrificing the remarkable position which has been attained in efficiency.

It is too early to expect the full effect of the benefits ultimately to be derived from interconnection; only in time will these principles and the corresponding practices be reflected in their entirety on system layout and apparatus design.

A broad decline in the price of energy and in the price per kilowatt for practically all lines of electrical equipment is the surest indication that the public utilities and the manufacturers are united in a relentless striving toward greater efficiency in all operations; with the resulting savings passed on to the ultimate consumer as a matter of policy. M. O. Troy

The Changing Trend in Insulating Transmission Apparatus

By D. M. JONES

Central Station Engineering Department, General Electric Company

TO one closely associated with the day-to-day phases of any activity, the full significance of the passing events is often obscured by the knowledge of the details of the events themselves. As the old phrase has it: "One can't see the forest for the trees."

This truth, in conjunction with the general realization that changes in the requirements of transmission-apparatus insulation have been frequent and continuous of late, leads one to suspect that it may be well to review this situation with an eye to discovering if history may not be in the making under our very noses.

In determining the path of progress, be it of a star in the heavens or of an idea in the minds of men, it is necessary not only to know where or what it is now, but also something of whence it came. Therefore, let us look first to the past.

It seems fairly clear, both from tradition and from the make-up of the A.I.E.E. rules on the question, that insulations were originally established with reference to the maximum dynamic voltage to which it was expected they would be subjected. Thus, on early three-phase circuits, which were generally considered as ungrounded and usually were delta connected, the maximum-voltage condition was considered as occurring when one conductor was earthed by some circumstance and line-to-line voltage could appear between the other two phase conductors and ground. Line-to-line voltage thus became the maximum voltage criterion, and the standard insulation test was taken as twice this value for ordinary apparatus and 2¼ times for "protective" apparatus.

This viewpoint stood unchallenged until the transmission of electric power developed sufficiently to encounter the arcing-ground phenomenon with its trick of producing excessive overvoltage which often worked much damage to insulation of one type and another. The popular cure for this proved to be a departure from the original ungrounded system. The trend was accentuated by the realization that this practice increased the degree of reliability with which relays and oil circuit breakers would clear the proper section of a system on which insulation breakdown occurred.

The application of the grounding idea soon raised for consideration the conception that a circuit or a system, which was no longer delta but Y-connected with its neutral point directly connected to ground, would be expected to experience line-to-neutral dynamic voltage as a maximum between any phase conductor and ground under the condition of one conductor becoming grounded, instead of line-to-line voltage as has been pointed out in connection with ungrounded circuits. When this was realized, it was soon suggested that the same logic used in originally establishing line-to-line voltage as the insulation test base for circuits in general would now imply leg voltage as the criterion for solidly-grounded circuits.

The complete acceptance of this view was opposed by some on the ground of natural conservatism and by others with the specific objection that the foregoing reasoning was based on a system having a zero-impedance ground at each apparatus location whereas, in fact, no such ideal condition could be produced and that the actual conditions would often fall far short of the ideal. The force of these objections as well as the logic of the basic idea were both recognized, so it was decided to compromise and permit as a special case (on high-tension circuits where the saving warranted the practice) apparatus insulation based on a value half way between line-to-line and leg voltages. Thus there came into being the "2.73 times leg voltage" test.

Increasingly, however, during this period, operating experience began to inject lightning into the picture as a cause of transmission-insulation breakdown. Although this source of overvoltage was quickly disposed of in the beginning by recourse to the legal expedient of relegating it into the unknown and unknowable, as an "Act of God," the later pioneering work of such engineers as F. W. Peek, Jr., and many others here and abroad reinstated it in the picture as a natural phenomenon largely capable of being handled.

Including lightning in the picture forced the recognition that, when present, it was the maximum breakdown voltage imposed upon insulation.

Qualitative thinking on lightning as a source of overvoltage soon led to the realization that this maximum insulation breakdown voltage, in any given instance, did not modify itself to match the dynamic voltage of any circuit or system, but rather for a given cloud condition occurred on an exposed line in proportion to the effective height of the line above the ground. As it was evident that the average height of conductors above ground did not follow the circuit voltage rating, those interested in the problem were faced with the additional difficulty that the probable lightning voltages would not be proportional to apparatus insulation which was based on rated voltages.

Besides this, it has also been recently pointed out that not only does lightning voltage depart from an exact relation to circuit voltage but also, in the case of ordinary transformers, which are known to present a resonating circuit to such voltage, it produces various values of impulse voltage and at various locations within a given transformer for a given value of applied impulse voltage, depending upon the slope and duration of the overvoltage impulse wave. Such viewpoints seemed at first but to compound the original felony of lightning itself.

The sting of the latter multiplicity of variations just mentioned has been largely drawn by the work of the transformer engineers of the Pittsfield Works of the General Electric Company in making a transformer non-resonating, wherein the stresses due to lightning would be evenly graded from the impressed voltage at the transformer terminal to zero at the point of ground attachment for the installation. (1)

In such a unit the insulation stress at every point is fixed in relation to the maximum stress applied to the line terminal and a precise distribution of insulation is thus possible.

The difficulty of the lack of proportionality between lightning voltages and insulation strengths which are based on circuit voltages is, however, still with us. The present considerable thought and discussion resulting from this situation uniformly leads back to a basic examination into characteristics of the overvoltages caused by lightning.

In briefest possible terms these lightning voltages appear to have about the following genesis:

Atmospheric masses of water vapor, which we normally term clouds, under certain circumstances evidently depart from a balance of plus and minus electrical charges. Such an unbalanced potential on a cloud makes it a charged object and around it in space, by virtue of this circumstance, arises a condition referred to as the existence of an electrostatic field. If there were two such similar clouds near each other charged equally but to opposite polarity, the voltage at any point in the field directly between them would vary from the potential of one cloud to the potential of the other cloud in an amount proportionate to the ratio of the distance of the point from the first cloud to the total distance between the clouds. At the mid-point between the clouds there would be a plane where the potential would be half-way between the equal and opposite cloud potentials, or zero. The earth's surface is often looked upon as a mammoth electric charge-equalizing reservoir which therefore has zero potential, and so corresponds to the zero-potential place between the two clouds. Thus, a cloud of either potential near the earth can be viewed as having a field between it and earth in which at any point the potential varies from the potential at the cloud to zero potential at the earth in proportion to the ratio of the distance of the point from the earth to the distance of the cloud from the earth.

When the charged cloud hovers over a transmission network, we have conductors supported above the earth's surface and these conductors, either by their direct copper connection through transformer-neutral grounding points or leakage over multitudinous insulation paths in parallel, tend to remain at ground potential; in which case a charge will appear on the conductor sufficient to offset the voltage that would normally be present in the cloud's field at that point if the conductor were not present.

If the cloud's field did not exist this charge on the conductor would not be present, and therefore if the cloud's field were suddenly removed this charge on the conductor would immediately try to disappear.

Whenever the cloud-field gradient becomes greater than can be withstood by the insulating medium between cloud and cloud, or cloud and earth, the medium breaks down and we have "lightning." This breakdown dissipates the charge on the cloud, and with the loss of the charge the field also disappears. This sudden elimination of field releases the charge on the conductor and it begins to flow along the conductor in a sudden rush to earth. This flow in overcoming the impedance of the conductor develops a high voltage and at a rate of rise that represents a very high frequency or a steep wave-front.

Thus, we have waves of electrical energy the voltages of which rise in few microseconds to high values originating on a transmission system incident to lightning strokes (that do not themselves hit the system) and then, seeking a lower potential level, travel over all available paths until they finally reach the earth or are dissipated in losses incident to their journey.

This is the overvoltage "induced" by lightning.

If the cloud discharge had chanced not only to flash to earth but also to actually approach the ground via the conductor, it is conceivable that when the flash reached the conductor the potential drop along the arc path would be less than had previously existed across that stretch of the electrostatic field before it broke down in the arc. This being the case, the conductor at the instant the arc struck it would have impressed upon it a voltage higher than that corresponding to the charge on it due to its position in the field; and thus, being in path of an arc, would normally give a much higher potential on a conductor than the induced potential caused by lightning striking elsewhere.

This is the direct-stroke phenomenon.

The induced overvoltage incident to lightning, as we have seen, normally originates on transmission conductors and imposes itself on apparatus only as it travels from the original point in search of ground.

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(1) "The Effect of Transient Voltages on Power Transformer Development," by K. K. Paluefl, *A.I.E.E. Transactions*, 1st quarter, 1929; also "Lightning Study on Transformers with Cathode-ray Oscillograph," by F. P. Brand and K. K. Paluefl, A.I.E. E., 1929.

This overvoltage is thus a basic factor in affecting both conductor and apparatus insulation.

The problem of conductor insulation spill-over, which is normally synonymous with transmission-line insulator flashover, is primarily one of reliability of service and only secondarily one of protection of line insulation against damage, since insulators only occasionally break when they flash over and even then can be replaced at relatively low cost.

A reduction in the number of line flashovers in order to increase reliability of service is of basic and growing importance, for reliability now seems to be the basic criterion that will determine the ultimate scope of application of long-distance transmission as opposed to short-distance transmission with its necessarily greater number of generation locations.

From the foregoing general picture it is evident that to reduce the number of flashovers on a given line, the following principles are applicable:

(1). Keep the line away from storms.

This may not be as foolish as it sounds. Certainly too many transmission lines have been built without any attempt to dodge known storm areas, and too little is known as to what areas are storm areas.

(2). Bring the conductor and earth as near together as possible so that the voltage induced by a given cloud condition may be minimized.

This, of course, is accomplished either by bringing the conductor nearer to "ground" or the "ground" nearer to the conductor.

The first suggestion is met by constructing lines at the minimum allowable clearance above the earth. Line construction appears to be swinging in this direction to some degree, after having practically gone to the other limit during a period when the base criterion for proper line construction seemed to be the minimum cost for supporting conductors of certain current-carrying capacity between two geographic points. This test generally led to a minimum number of supports per mile, located on the top of every available rise of ground. This, of course, produced maximum storm exposure and resulted in an appreciable reduction in ultimate line reliability and, therefore, in actual line value. It is at least evident that these extreme "Roof of the World" lines are no longer in high favor.

The reciprocal suggestion of bringing the earth to the line is very rationally and effectively accomplished by the use of ground wires and is inadvertently attained to a fair degree locally by the supporting structure itself normally appearing in outdoor switch yards. The ground wire persists as a major instrument for reducing lightning potentials on transmission lines, but it is changing in makeup from a rigidly supported guy strand toward a flexibly supported conductor. This transition is fostered by the experience that a ground wire of reasonable current-carrying capacity helps in distributing ground-fault currents over several structure-to-ground paths, which equalizes the effective structure-to-ground resistances throughout the line and also, by lessening the ground-fault current flow per footing, reduces the potential gradient near structure footings. In addition, the ground wires in approaching the make-up of the regular conductor tend to approach it in physical characteristics, such as sag, both under normal and emergency loading, swing by wind, and resistance to corrosion.

Departure from similarity in those physical characteristics has often proved disastrous by causing ground wires to become a menace to conductors under other than lightning conditions.

(3). Increase line insulation so that it will take more voltage to flash it over.

Since lightning voltages vary over a wide range, this change would eliminate many flashovers. This is so evident an answer and so easy and cheap in application, up to the clearance limits allowed by the supporting structure, that it has been widely used. It does not, however, seem that it can be applied to a sufficient degree to accomplish the desired ultimate of eliminating all flashovers.

(4). Use protective devices for quenching the flow of the dynamic current over the line insulator, following the flashover of the induced charge.

Two outstanding devices of this type are the Petersen coil and the fused flashover gap on a line insulator.

The Petersen coil has been widely applied in Germany to circuits ranging from low-voltage cable to 220-kv. transmission; and very satisfactory results are claimed for it. It has never been given any considerable trial in this country, although what experience has been gained was favorable.

The fused flashover gap on line insulators is now in the early trial stages and, therefore, its possibilities are not yet determined.

(5). Apply distributed lightning arresters on the transmission line itself to prevent the formation of sufficient voltage to spill over the line insulation.

This attack has frequently been made on local bad spots on lines but so far has never been comprehensively tried out over an area.

As already discussed, it is evident that not only is there no well-defined maximum limit to lightning potentials induced on conductors but also, as earlier suggested, even the average value of these potentials may not tend to match up with the various apparatus insulations for different voltage classes.

This at first would seem to give the magnitudes of induced lightning voltages a very elusive status. Fortunately, however, as is thought to be fairly evident from the foregoing, the magnitude of potential that can be impressed upon any piece of transmission apparatus by these induced waves of electric energy is limited to the maximum impulse voltage permitted either by adjacent protective devices or by the flashover value of adjacent insulations, as the case may be. As these values can not only be reasonably established but also reasonably adjusted, as desired, it is thus possible to control induced lightning potentials impressed upon transmission apparatus. This makes it feasible, by properly adjusting the adjacent line insulation or voltage-limiting devices, to continue in the matter of transmission-apparatus insulation with the convenient well-established present scheme of relating apparatus insulation strength to apparatus class voltage.

In establishing the make-up of this insulation-strength criterion, it is being recognized that the consideration of lightning voltage requires something in the criterion to fix the impulse strength of transmission-apparatus insulation. It now seems that this will probably be accomplished by adding to present standard 60-cycle test requirements for insulation for each class voltage a minimum allowable impulse breakdown in terms of a string of insulators having a certain defined 60-cycle test value. This will largely eliminate the variation in impulse breakdown value of insulation with different wave. Once this is accomplished there will be a standard impulse strength for transmission apparatus for every voltage class.

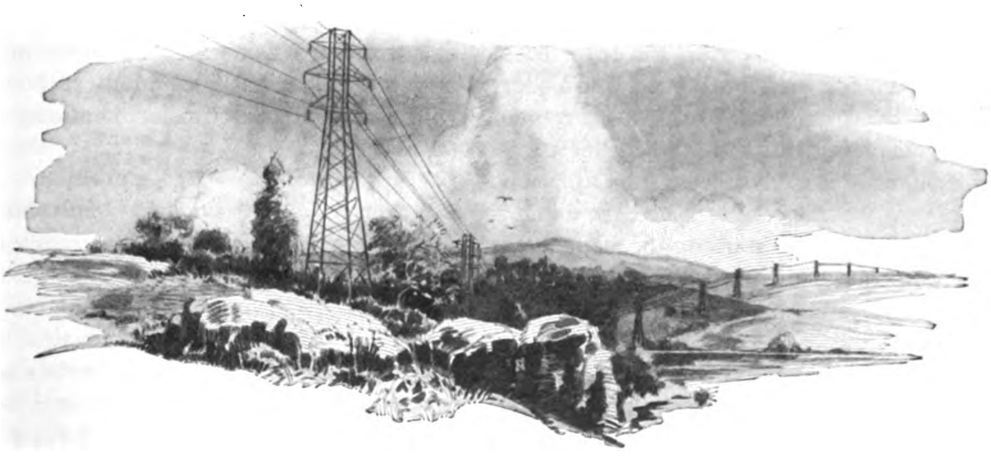
Inasmuch as the present major basis of transmission design is reliability, the transmission system designer's ultimate aim is—no flashovers on normal-line insulation and certainly no flashovers in switch and transformer yards. Such an aim leads to insulating a line on its own basis, while the outdoor-yard apparatus according to this trend will normally have a standard impulse insulation strength for a given class voltage. On this basis of desiring to eliminate all yard flashovers, there is little justification for making minor gradations in impulse strength between various insulations within the yard. The single yard insulation level becomes more and more rational also in the light of actual percentage accuracy of the general mass of insulation impulse-voltage breakdown values. Such a procedure will not only be convenient but will also give the industry the benefit of some reasonable degree of standardization of transmission apparatus with its ultimate resultant reduction in apparatus costs.

It is already evident that in general the line insulation levels thus arrived at will exceed the yard levels. This simply means that something must be interposed between the transmission line and the yard which will reduce all transmission lightning voltages to a level acceptable to the yard insulation. As in general the number of lines connected to a switching or transmission yard increases with the yard area, it will normally result in there being a lightning-voltage-limiting device per unit of area of yard, so that the tendency in this practice will be to have no piece of apparatus very far from such a protective device.

In some of these outdoor yards, notably those directly associated with hydro generating plants, it occasionally happens that because of the necessary distance between the plant and the yard, the step-up transformers are located at the generating location and connected to the yard through high-tension lines. In such an arrangement the transformer installation at the generating station becomes simply a unit outdoor yard in principle and the protective reasoning that has been outlined can be still applied.

Direct strokes must also be considered in transmission design. Although they occur on most lines but infrequently, they are far more severe than induced strokes. This phase of the general lightning problem has already been given considerable thought in oil-storage-area lightning protection and even in the case of some substations. The remedies so far have been various applications of the general principle that if a preferred path is presented to a cloud-to-ground flashover, adjacent poorer paths will not be used by the arc. Thus, a conducting tower will protect a certain adjacent area from direct stroke.

Thus far have we come from the days of Franklin with his key on a kite string.



The Double-winding Generator

General Principles—Short-circuit Kv-a. in Various Systems—Switchgear—Bus Voltage Control—Actual and Proposed Installations—Tests

By T. F. BARTON
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THE double-winding generator (Fig. 1) provides two independent windings for connecting to separate sections of a bus or for connecting to separate loads. Each of the individual windings may consist of one or more circuits. Each winding may be loaded without regard to the loading of the other, provided neither winding is overloaded and therefore that the simultaneous loading of the two windings does not exceed the overall rating of the generator.

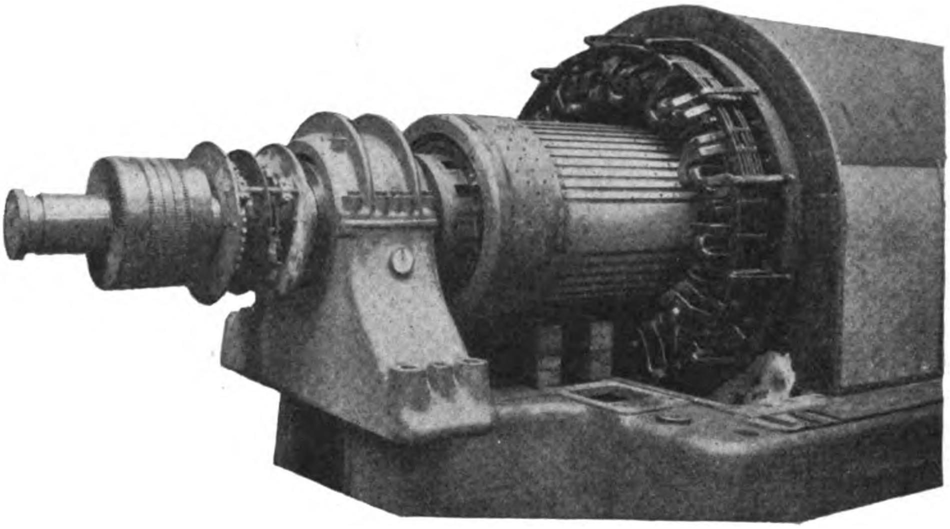


Fig. 1. A View of the 83,333-kw. Double-winding Generator with Rotor Partially Withdrawn, Showing Special End Connections

For equal loading and the same power-factor, the voltage and phase of the two windings are equal. For unequal loading or loading at different power-factors, the voltage of the two windings will be unequal in value and displaced in phase. The magnitude of phase and voltage difference is determined by the constants of the circuit and the current and power-factor of the load.

Station bus bars have served to connect machines together for synchronizing purposes, for transfer of power along the bus, for distribution to the feeders as required, and to provide a physical means of connecting the generating units to the feeder units. The simple bus bar was used successfully until the concentration of power connected to it became dangerous or difficult to handle without undue expense in the switchgear associated with it, or the possibility of resultant damage to connected apparatus, such as cables, generators, etc.

At this point in the development of the central station it became necessary to provide suitable current limiting reactors in the bus structure, as well as in the circuits connecting to the structure, to limit the total flow of energy to the point of fault. For approximately twenty years this form of protection has been used with great success; and the need for a more effective system of reactoring has only recently appeared.

Generator Reactance

The reactance characteristics which may be obtained on a modern 60-cycle generator of the double-winding type can be readily understood by referring to a conventional diagram of the three-winding transformer. The leakage reactance of each winding is shown as the reactance of two of the circuits and the reactance common to the two windings is shown as the reactance of the third circuit. Leakage reactances of 14 per cent may be obtained in each winding and 5 per cent reactance in the common branch. From these figures it is evident that the flow of current from one bus section to another is limited by the sum of the individual reactances of the two windings so that a transfer reactance of 28 per cent is obtained.

Bus Reactors and System Short-circuit Current

Two general forms of bus reactoring have been used: The ring bus subdivided in sections with suitable reactors between each section; and the synchronizing bus and feeder bus in combination, with generators connected directly to the feeder bus sections, and the various sections connected through suitable reactors to a synchronizing bus. The former arrangement is used very much more generally than the latter.

The very rapid increase in the individual size of generators has increased greatly the capacity connected to the individual bus section, resulting in the need of very large reactors for bus synchronizing purposes as well as the need for switchgear of very large current capacity and high interrupting capacity.

The first use of the double-winding generator has eliminated the bus section reactor and has halved the ampere capacity required of the circuit breaker at the same time materially reducing the interrupting capacity required of the breaker for a given capacity of connected apparatus.

To show clearly the reduction in short-circuit kv-a. made possible by the use of the double-winding generator, three typical diagrams of connections are shown in Fig. 2. System *A* is the conventional ring bus with bus section reactors. Each section is supplied by a 100,000 kv-a. unit of the conventional type. System *B* uses the synchronizing bus with reactors between each combination generator-and-feeder bus section and the synchronizing bus. System *C* is the ring bus without bus reactors, but with the double-winding generator.

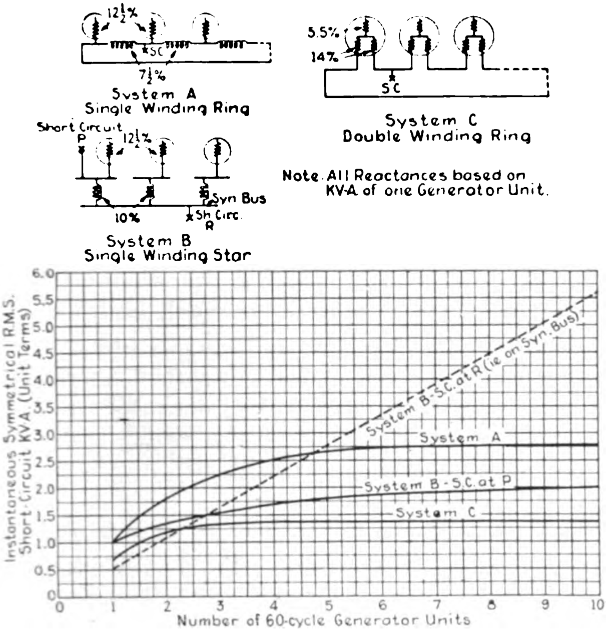


Fig. 2. Diagrams of Connections and Corresponding Time-current Curves for Three Typical Generator Systems

The short-circuit current in each system is shown in relation to the number of generators connected to the bus. In System *A* the short-circuit kv-a. increases up to a total of six machines, after which practically no increase in short circuit-current is encountered with an increase in connected capacity.

In System *B* the short-circuit current on the feeder sections is much lower than in Section *A* and increases gradually with an increase in connected capacity. In this system the concentration of power occurs on the synchronizing bus; and unless the synchronizing bus is reactored there is a limit in the amount of capacity which may be connected to it.

System *C* shows a much lower short-circuit kv-a. than either Systems *A* or *B* and the amount of short circuit kv-a. does not increase with the addition of connected capacity after a total of four machines is reached. The increase resulting from the change from two machines to four machines is small and of the order of 8 per cent.

It should also be noted that in System *A* the generators are synchronized with each other through the included reactance in the bus sections. Similarly, in System *B* they are synchronized through the included reactance to the synchronizing bus, while in System *C* the generators are synchronized without any included reactance. In System *C*, therefore, much better synchronizing is obtained between the units; and the high reactance between bus sections interferes only with the transfer of power from bus section to bus section and short-circuit current from bus section to bus section, but not with synchronizing power from generator to generator.

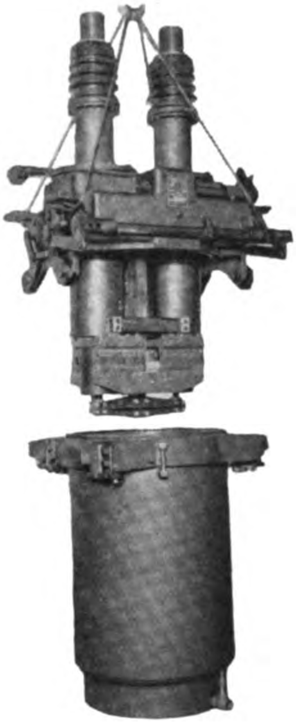


Fig. 3. A 15,000-volt, 5000-amp. Circuit Breaker of the Type which Will be Used with a Two-winding Generator

TABLE I

SHORT-CIRCUIT KV-A.

	System *A*	System *C*
Instantaneous Unsymmetrical	3,120,000	1,840,000
0.1 second later	2,580,000	1,520,000
0.4 second later	1,510,000	900,000
Sustained	600,000	525,000

Comparing a 3-phase bus short circuit in Systems *A* and *C*, the values given in Table I apply.

In this table it should be noted that System *C* has an intantaneous short-circuit kv-a. of approximately 59 per cent of System *A*, while the sustained current is approximately 87.5 per cent, which means that even though the maximum short-circuit kv-a. is greatly reduced, the sustained level of voltage for feeder short circuits (provided feeder reactors are used) is only slightly lower than obtained in System *A*.

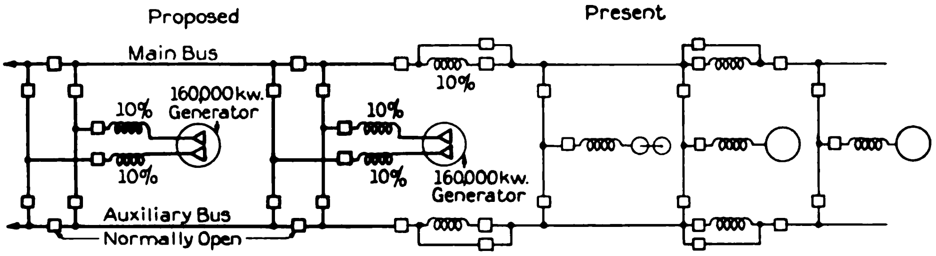

Proposed
Present
Main Bus
160,000 kw. Generator
10%
10%
10%
10%
10%
160,000 kw. Generator
Auxiliary Bus
Normally Open

Fig. 4. Diagram of Connections for a 25-cycle, 160,000-kw. Unity Power-factor 11,400-volt Double-winding Generator

The voltages of the unaffected bus sections are maintained at a materially higher level than would be established in System *A*.

Switchgear Current Ratings

A number of difficult problems are faced in the manufacture and installation of high-ampere-capacity switchgear. In general it is easier to provide high ampere capacity in the type of switchgear which does not carry the entire load current through the circuit interrupting element of the oil circuit breaker, and even with this type of breaker the advisability of providing continuous current-carrying capacity of more than 6000 amperes at 60 cycles is debatable.

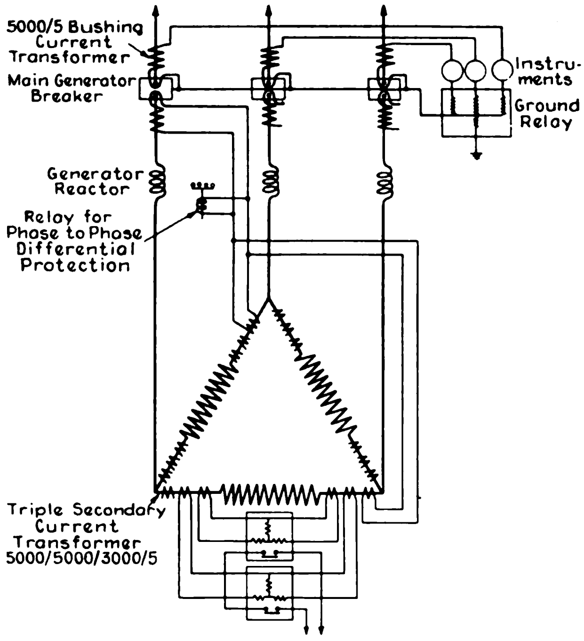

5000/5 Bushing Current Transformer
Main Generator Breaker
Instruments
Ground Relay
Generator Reactor
Relay for Phase to Phase Differential Protection
Triple Secondary Current Transformer 5000/5000/3000/5

Fig. 5. One Half of a Double Winding of a 160,000-kw. Generator Showing Relay Connections for Differential Protection

Tank-type breakers have been built for both 25 and 60 cycles with current ratings up to 5000 amperes. Fig. 3 is a photograph of a 5000-amp., 25-cycle unit at 15 kv., which will be used in connection with a 160,000-kw., two-winding, 25-cycle generator. The photograph gives a fair idea of the size of bushings and the large amount of copper required for carrying the current.

In a high-capacity 13.8-kv. system the magnetic stresses and thermal effects may be as much of a limiting factor as the kv-a. interrupting capacity of the switchgear. The double-winding generator is particularly effective in reducing the instantaneous short-circuit values, and provides a much needed relief in solving this phase of the short-circuit problem.

Switchgear is stressed in closing a circuit as well as in opening a circuit, and it is very desirable to limit the current which may flow when a switch is closed on a circuit that is short circuited.

Bus Voltage Control

In the conventional system, the bus voltage is controlled by regulating the voltage of the individual units connected to the bus. Any difference in voltage existing between bus sections appears as drop across the bus section reactors. Voltage control of the individual bus sections is not so flexible when the double-winding generator is used, since the excitation in this case is applied at the center point of the reactance connecting bus section to bus section. The individual bus section voltages, however, may be controlled within limits by varying the excitation of the machines involved and is accomplished by assigning a unit for the control of each bus section, with the result that the power-factor of the load in the two

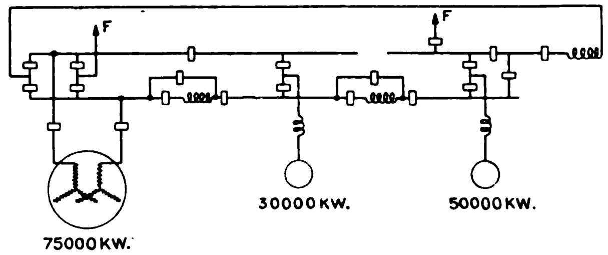

F
F
75000 KW.
30000 KW.
50000 KW.

Fig. 6. Diagram of Connections for a 60-cycle, 83,333-kv-a. 13,800-volt Double-winding Generator

windings of the generator is modified sufficiently to produce the required voltages for each bus section.

Installations

There are two installations under way in which the double-winding generator will be used. A 25-cycle, 160,000-kw., unity power-factor 11.4-kv. generator will be connected as shown in Fig. 4. This huge generator will be arranged with two windings, each connected in delta. The delta connection proved to be more desirable than the usual star connection because of the large capacity and relatively low terminal voltage involved. The neutral for this system is obtained by means of grounding transformers; and it is necessary to provide a grounding transformer or its equivalent on each section of the bus, since the several sections are connected together through the generator and are therefore isolated from each other as would be the case if they were connected through a 1 to 1 two-winding transformer.

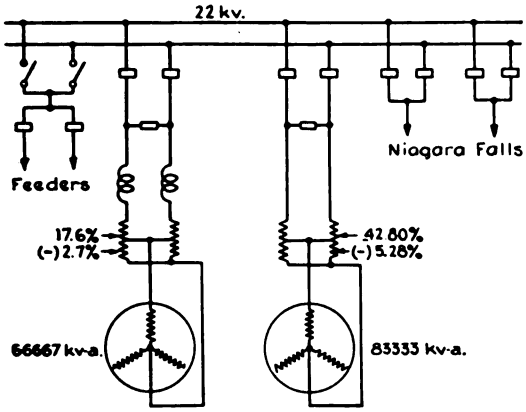


Fig. 7. Diagram of Station Connections, Showing Reactance Values of Autotransformers, for an Installation of Double-winding Generators

Each winding of this generator will be relayed as a unit according to the general scheme shown in Fig. 5. The scheme provides protection for an internal fault in each phase and a fault from phase to phase. An alarm is sounded in the event of a ground on the generator leads. In case of failure to ground in one phase of one winding it is proposed to disconnect that winding but not to disturb the unaffected winding. In such a case the operator would provide for completely disconnecting the generator as promptly as system conditions permit. In case of a fault in both windings, or of a fault from phase to phase in one winding the unit is automatically disconnected. It is hoped that this sytem of relaying will result in disconnecting from the system the minimum amount of generating capacity which the occasion requires and at the same time not subject the equipment as a whole to any undue hazard.

In the second installation, a 60-cycle 83,333-kv-a. 13.8-kv. double-winding generator will be connected as shown in Fig. 6. This machine replaces a 35,300-kv-a. unit and makes use, with some sacrifice in flexibility, of a large part of the switchgear as originally installed. In this case both the ampere capacity and the interrupting capacity of the switchgear were involved.

The feeders are arranged with selector switches so that the amount of load may be adjusted to some extent by transferring feeders from one bus section to the other, thereby distributing the load on the two windings of the generator.

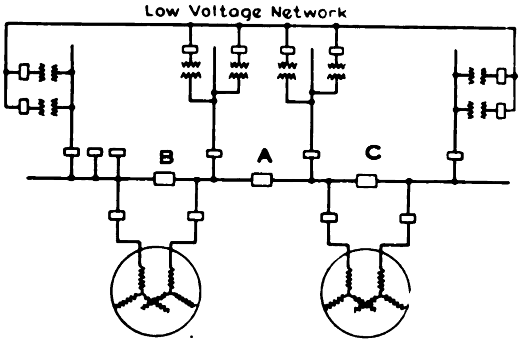


Fig. 8. Diagram of Connections of Double-winding Generators for Supplying a Low-voltage Network

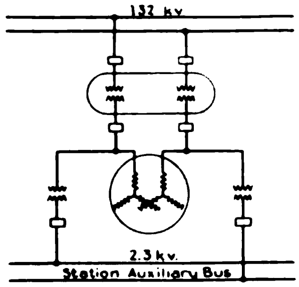


Fig. 9. Diagram of Connections for the Application of the Double-winding Generator to High-voltage Systems Through the Use of a Four-winding Transformer

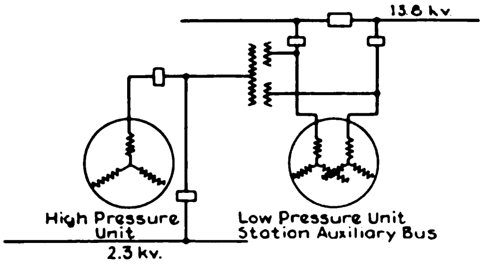


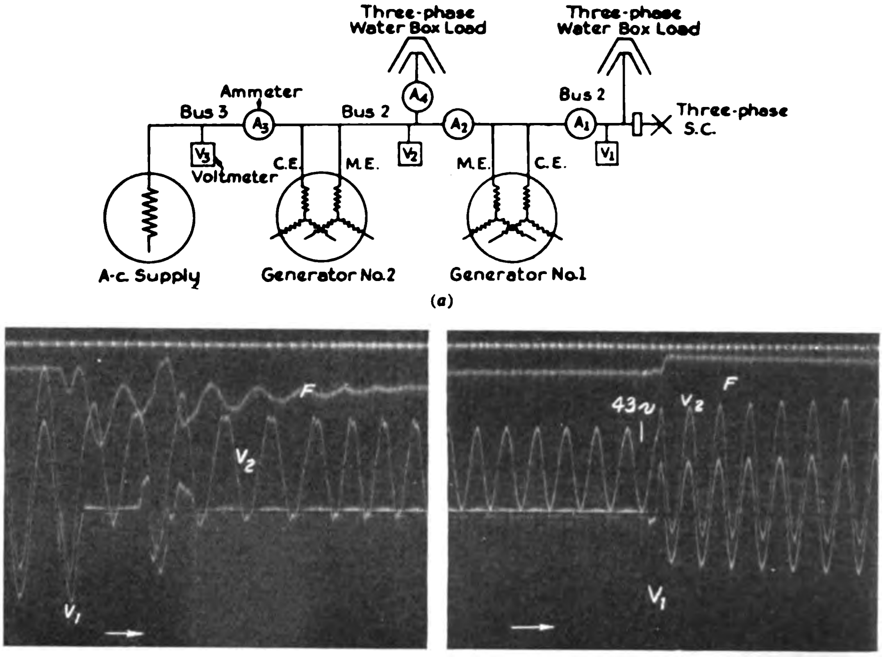
Fig. 10. Diagram of Connections for the Application of the Double-winding Generator in Connection with a Three-winding Transformer

For systems using station voltages higher than generator voltage, characteristics similar to that of the double-winding generator may be obtained by a two-winding autotransformer or a three-winding transformer. There are now in operation two generators with the double-winding autotransformer supplying power to two sections of a 22-kv. 25-cycle system. One generator is rated 83,333 kv-a. and the other 66,667 kv-a. Station connections and reactance values of the autotransformer are shown in Fig. 7. The autotransformer for the larger generator was originally designed for the two-circuit operation, whereas the autotransformer on the smaller generator was reconnected, and since reactance of the proper value could not be obtained in the transformer, external reactance was placed in each circuit.

When autotransformers or transformers are used, unbalanced capacity can be provided at a more reasonable cost than when it is provided in each of the generator windings. In the two generators now under construction, the maximum capacity in either winding is approximately 55 per cent of the total machine rating.

Proposed Applications

Two general system plans have been used, one the so-called "loosely-linked" system and the other the "closely-linked" system. In the latter some effort is now being made for synchronizing at the load, which in general means synchronizing at the low-voltage bus of the substations and which in the future may mean synchronizing at the low-voltage a-c. network. These modifications are being made for the purpose of reducing the short-circuit kv-a., and if it is successful two of the uses of the generating station bus are eliminated. In this new system, power from the generator is transmitted over the feeders associated with that generator to the load. Moreover, each generator is synchronized at the load and must operate successfully during abnormal conditions with relatively high reactance between its terminals and the point of synchronizing. Fig. 8 shows the two-winding generators connected to a low-tension network. If all station bus switches are eliminated, a unit in the system consists of one half of a generator, a feeder bus, feeders, network transformers, and network protectors. If bus section switches are used as shown and with



(b)

Curve *F*: Field current, Generator No. 1.
Curve V_1: Line-to-line voltage on short-circuit winding.
Curve V_2: Line-to-line voltage on winding not short-circuited.

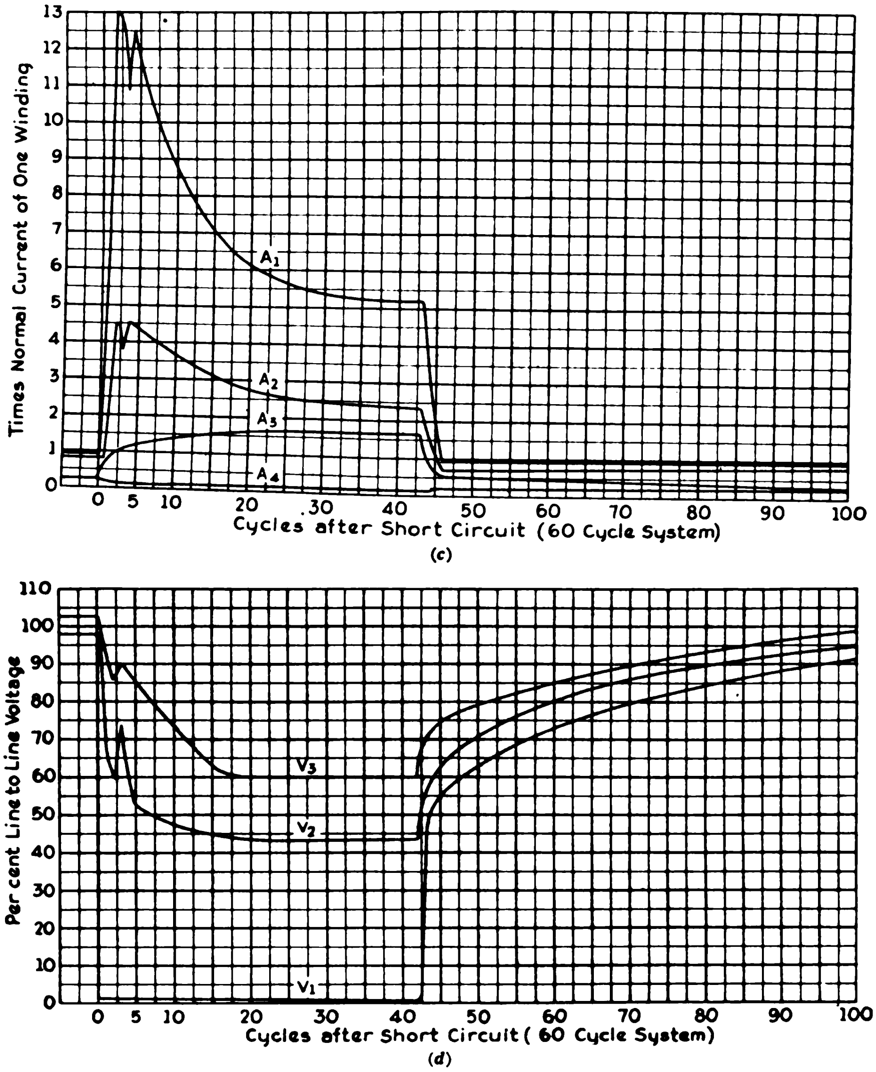
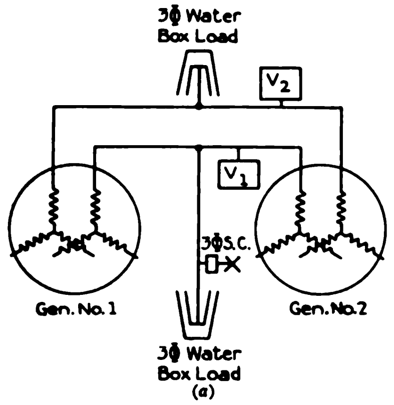
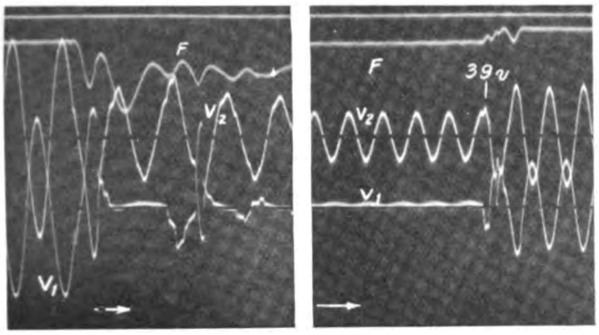


Fig. 11. Diagrams, Oscillograms, and Curves Relating to a Three-phase Bus Short-circuit Test of Double-winding Generators

switch *A* normally closed, switches *B* and *C* open, then a unit in the system is the same as in the preceding case, since the opening of the generator switch, switch *A*, feeder switches, and network switches would clear the section.





(*b*)

Curve *F*: Generator field current.
Curve V_1: Line-to-line voltage on short-circuited winding.
Curve V_2: Line-to-line voltage on winding not short-circuited.

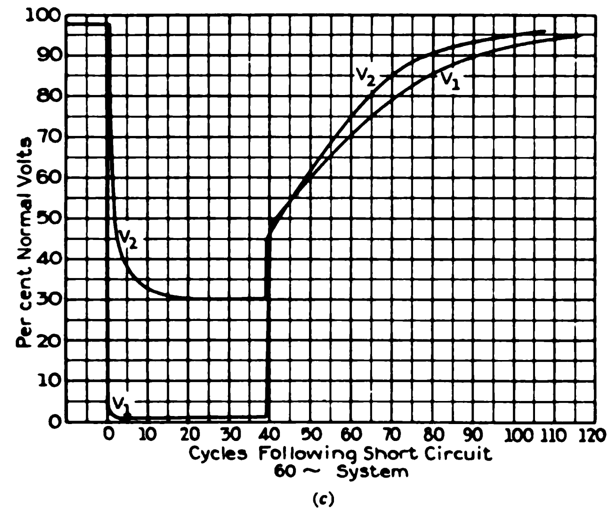


Fig. 12. Diagrams, Oscillograms, and Curves Relating to Tests of Double-winding Generators in Closed-ring Bus Connection

The double-winding generator in this system has the advantage of reducing the unit capacity in the system to one half of what it would be with the conventional type of generator and provides for a more flexible system in that as generating capacity is removed it is not necessary to disconnect the corresponding feeder and distribution transformer capacity. There is a tendency to increase the size of generating units; and while the size of the generating unit may be increased to advantage with regard to overall cost and economy of the unit itself, it may be desirable to subdivide the electrical end of the unit so that the electrical unit of the system is not of excessive size.

The outstanding advantages of the two-winding generator in this system are as follows:

(1). The several generators are synchronized at the station through no included reactance.

(2). The electrical unit in the system is reduced to one half size.

(3.) The short-circuit current from any section is in general no higher than would be obtained if the conventional generator were used and synchronized only at the load, since the reactance of the system connections between machines will probably be of the same order as the through reactance of the double-winding machine.

A number of large plants are being constructed to deliver their entire output at high voltage. In the past some of these plants have synchronized at the high-voltage bus, while other plants have synchronized both at the high-voltage bus and at the generator-voltage bus. The advantage of synchronizing at the generator voltage bus is an improvement in stability among machines at the time of fault on the high-voltage system. Fig. 9 is a proposed arrangement for the use of the double-winding generator with a four-winding transformer supplying power to two bus sections at 132 kv. With a short circuit on either bus section not only is the concentration of power reduced to a minimum, but the remaining bus section serves as a synchronizing bus for the generator.

Station auxiliaries in this system may be supplied by a transformer connecting directly to the generator leads of each winding. With the load of the station auxiliaries divided between the two 2.3-kv. buses, continuity of service is practically assured, since the voltage of one or the other bus will be practically maintained with the fault on the high-voltage system. The four-winding transformer may be of two-legged construction, with the primary and secondary of the transformer for one circuit on a common leg so that the reactance between the primary and secondary of one circuit is of the order of 18 per cent, whereas the reactance between the primaries or the secondaries of the two legs is of the order of 100 per cent.

Turbine-driven generators designed for 1200-lb. steam pressure are usually of the "cross-compound" or "steeple-compound" type. The division of load between the high-pressure unit and the low-pressure unit is in the ratio of approximately 1 to 3. If such a plant uses electric drive for auxiliaries, about one-third of the high-pressure unit output is required for auxiliaries; which suggests connecting the high-pressure generator directly to the station auxiliary bus at 2.3 kv. and connecting the high-pressure and low-pressure units together through a suitable transformer. If the double-winding generator principle can be used to advantage, then the low-pressure element is fitted with a double-winding generator and the high-pressure unit is connected to it through a suitable three-winding transformer. This transformer handles the remaining output of the high-pressure unit above that required for the station auxiliaries. With the high-pressure element connected directly to the station auxiliary bus, the voltage of this bus is stabilized and the power supply to the station auxiliaries is made more reliable. Fig. 10 shows one of the possible arrangements.

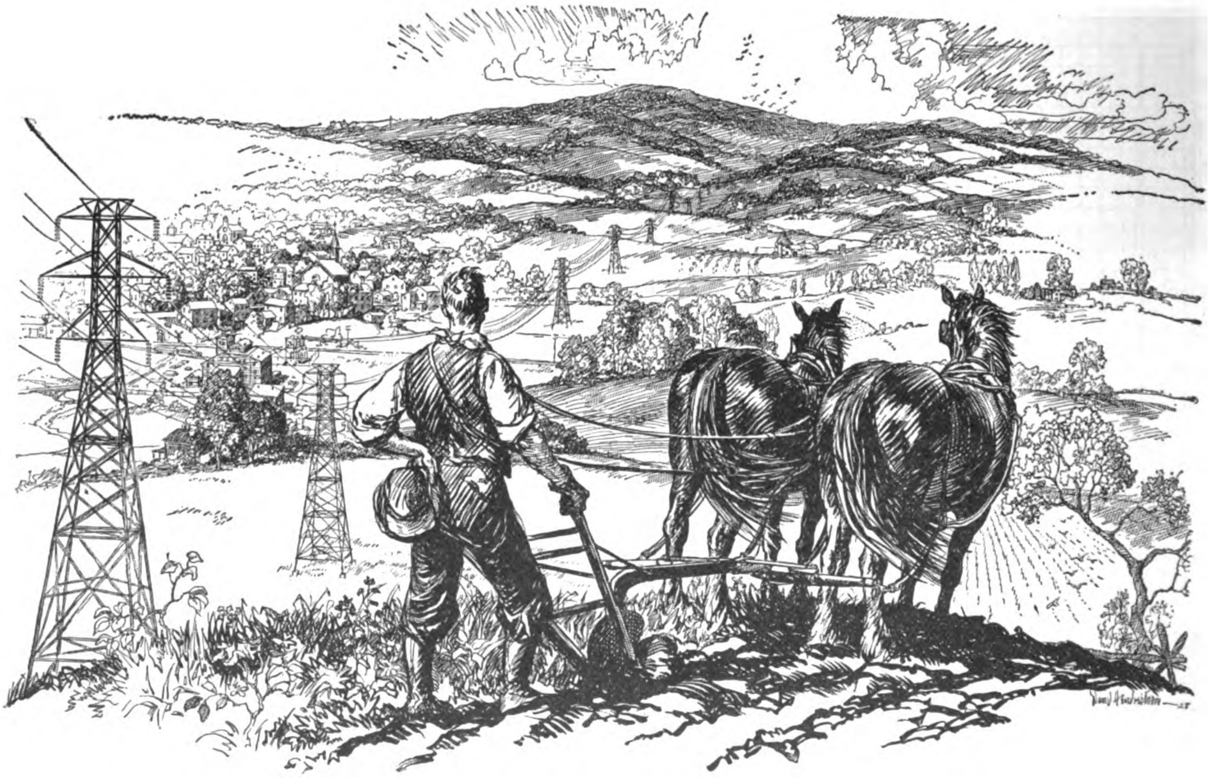
Results of Test

Two model turbine-driven generators provided with double windings were tested under short-circuit conditions to indicate the performance of this type of machine. The rating of each machine is 250 kv-a. at 60 cycles and 250 volts. The rating of each winding is 125 kv-a. at 250 volts. The reactance of the individual winding and the mutual reactance of the two windings is approximately that of the large 60-cycle turbine-driven unit, making it possible to obtain characteristic performance from tests on these small machines.

The diagram of connections for one important test together with voltage and current time curves are shown in Fig. 11. The test involves a 3-phase bus short circuit which remained on the system for 43 cycles (0.72 sec.). At the expiration of this time the fault is cleared by the opening of a switch.

Steady-state conditions are reached in approximately 30 cycles (0.5 sec.). The three generators operate successfully in parallel throughout the period of the test and continue in normal operation after the fault is removed. Some of the oscillograph records are included to show in detail the currents and voltages in the various parts of the system.

The electrical connections and performance of the two double-winding generators connected in a closed ring and with a 3-phase short circuit on one section of the ring bus are shown in Fig. 12. The arrangement differs from that of the preceding test in that no external source of power is connected in parallel with the two generators, and the bus ring is closed. The voltage of the unshorted bus section drops to 30 per cent at the end of 20 cycles and remains at that level until the short circuit is open at the end of 39 cycles. The voltage of both bus sections then increases toward normal and the machines continue to operate successfully in parallel supplying load to each of the bus sections. Some of the oscillograph records showing in more detail the conditions which existed during the test are included.



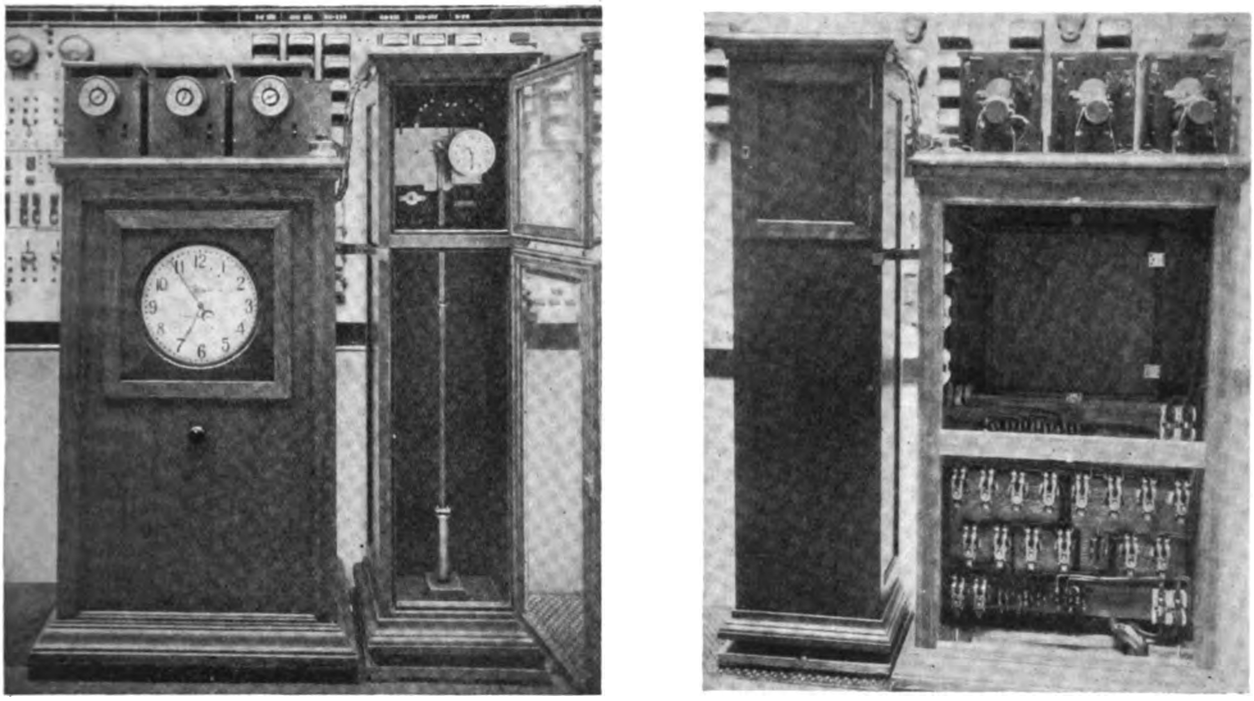
Automatic Control of Frequency and Load

Present Demands for Load Division and Frequency Control—Devices for Automatic Control—Description of Equipment—Operation of Equipment—Illustrative Example of Control—Installation of Control System

By H. A. McCREA
Central Station Engineering Department, General Electric Company

THE past few years have brought many evidences of the striking growth in the electrical industry. Not only has the size of individual stations increased, but interconnections between stations and between systems have greatly multiplied. These developments, of course, enable the various operating companies to effect economies in operating costs, and give greater reliability, due to the more diverse sources of supply. These same factors have also greatly increased the problem which must be solved in the operation of such an interconnected system.

One of the most important problems confronting the system operator is the control of frequency and control of the division of load between various stations or between different parts of an interconnected system. In operating any system, aside from the reserve to meet emergencies, it is necessary to operate certain machines at partial load so that sufficient capacity will be available to meet any expected changes in load, this additional capacity being so distributed that any increase in load may be picked up without overloading the tie lines. This is especially true where two power systems are connected together by a tie line of limited capacity. An arrangement which would enable certain designated stations to share proportionally any change in system load and permit each division of an interconnected system to pick up its share, and at the same time maintain system frequency, should appeal to operating engineers.

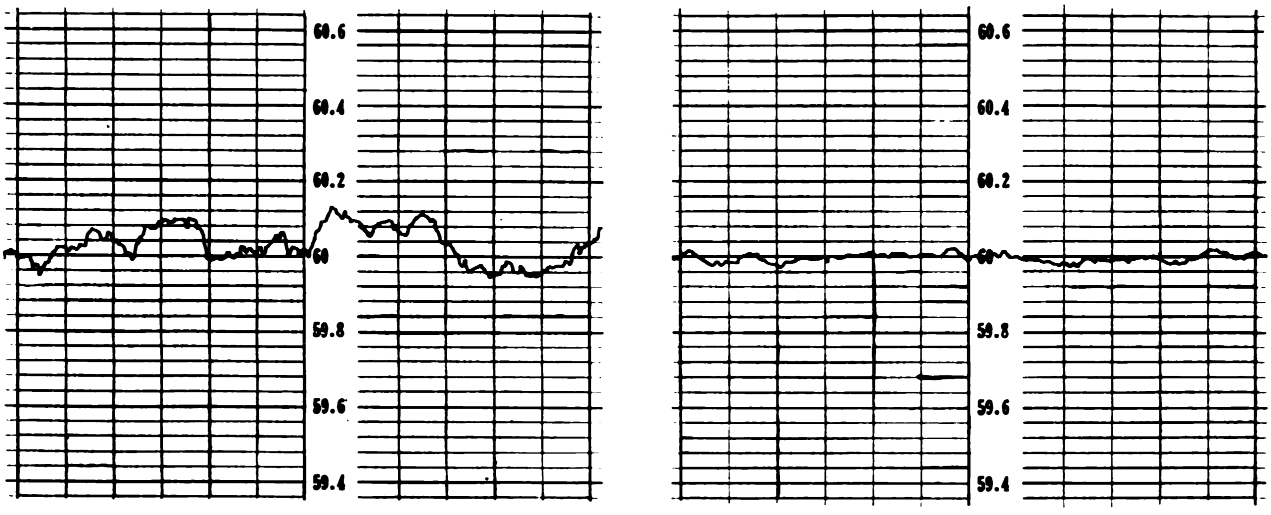

Front View

Rear View

Fig. 1. A Developmental Installation of Warren Frequency Control Equipment for Three 35,000-kv-a. Turbine Units Installed in the "L" Street Station of the Edison Electric Illuminating Co., Boston, Mass.

Through the joint efforts of the General Electric Company and the Warren Telechron Company there has been developed an automatic device (Fig. 1) for this purpose; and tests which have been made upon it indicate that it will meet these requirements. Fig. 2 shows portions of the frequency charts for the same system with manual control and with automatic control. For these load conditions, the automatic control limits most of the instantaneous frequency variations to a band of 1/20 cycle (plus or minus 1/40 cycle), while with manual operation variations of plus or minus 1/10 cycle or more are not uncommon. The use of the automatic control also relieves the operator from constant manipulation of the control switches, thus permitting him to give his attention to more important duties.

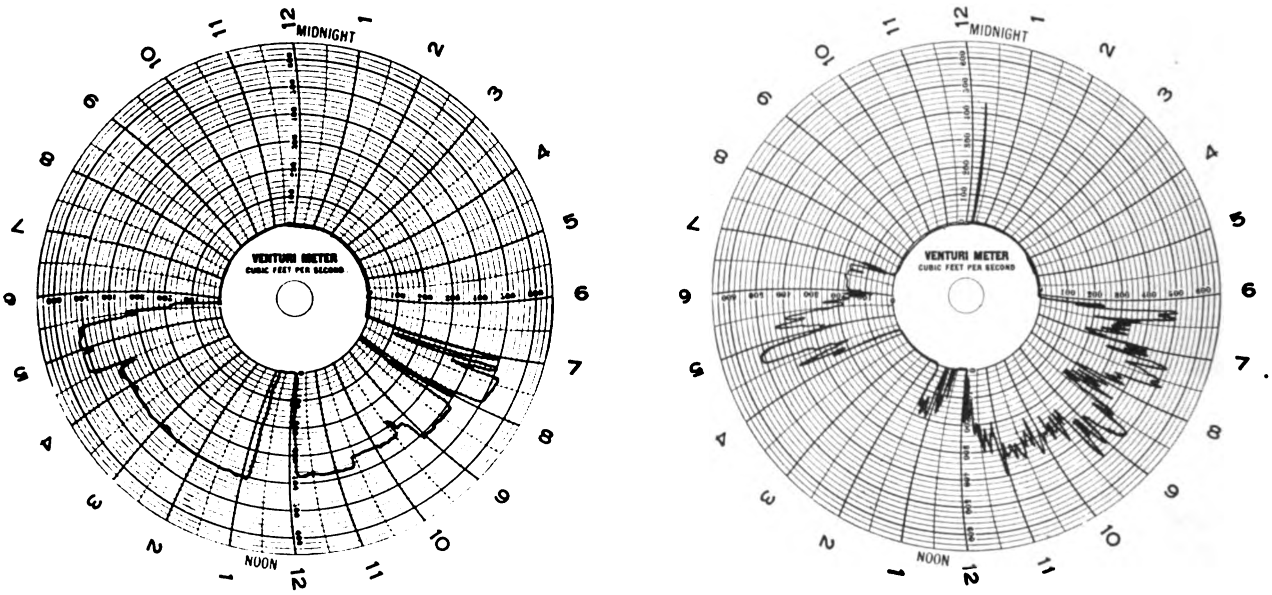
In the absence of wattmeter records, water-flow charts (Fig. 3) from a hydroelectric plant are included to show the fluctuations of load necessary to control frequency. The station at which these records were taken is a comparatively small part of the total system, about 5 per cent to 10 per cent depending on the interconnections. When operating under automatic control, this station takes all the load swings necessary to hold the frequency, the load on the other stations being picked up or dropped "in block" in accordance with a predetermined schedule.



Manual Control

Automatic Control

Fig. 2. Sections of Record Charts Showing Comparison of Manual and Automatic Control Over a Thirty-minute Period



Manual Control

Automatic Control

Fig. 3. Water-flow Charts Indicating the Loading on One Unit Under Manual and Automatic Control

The benefits from a single automatic device, of course, are limited to better frequency and as the automatic controller responds to very small changes in frequency the result is that, within limits of the station capacity, practically all the regulation is done by the automatically-controlled station. If, as will be shown later, the regulating duty can be divided among several stations, the result will be not only less severe changes in the load of the regulating stations but also a still better line frequency.

The frequency and load control system for a station consists of a master element known as the "Warren Master Frequency Controller," which determines the frequency error and the amount of correction required, and a "Warren Unit Load Controller" for each generator, which determines the division of load between the various units. The standard used to establish correct frequency is an accurate one-second pendulum having inherently a very high degree of precision. Fig. 1 illustrates a test installation of this system arranged for the control of three units.

The small dial in the clock case shows pendulum time. The three small dials at the top are mounted on the unit controllers and have two hands each, one indicating the throttle or waterwheel gate opening and the other the "integrated frequency" error, or the difference between the time set by the pendulum and the system time. The larger dial has nothing to do with the automatic control and simply keeps a record of the integrated error in the system frequency, using the pendulum as a standard of time.

The use of this equipment does not interfere in any way with the normal functioning of the standard governing equipment. The impulses to change speed or load adjustments are transmitted to the synchronizing motor on the governor, the connections used being very similar to those ordinarily used with manual control.

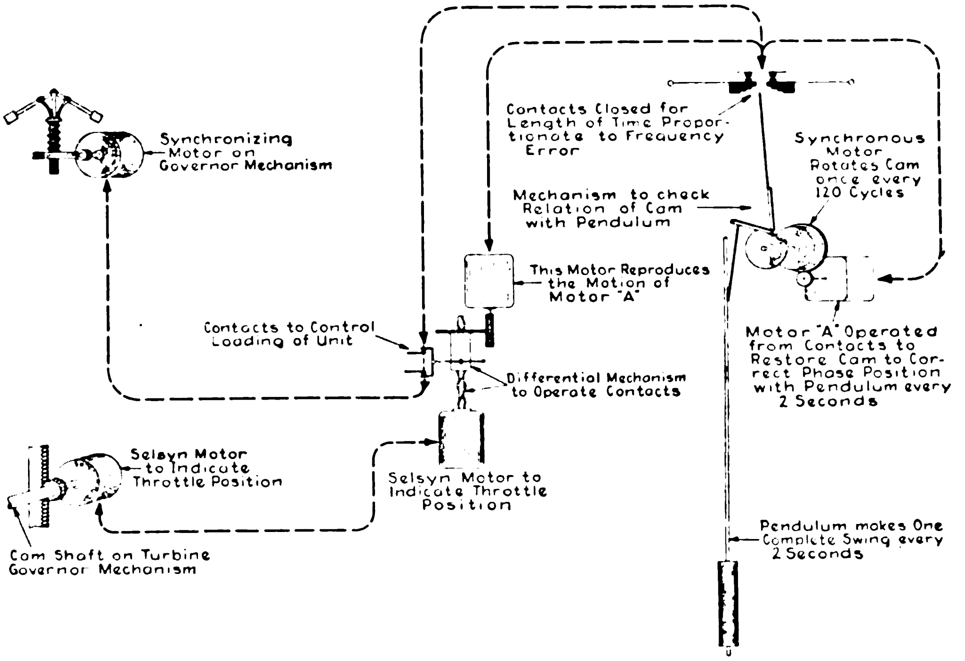

Synchronizing Motor on Governor Mechanism
Contacts Closed for Length of Time Proportionate to Frequency Error
Synchronous Motor Rotates Cam once every 120 Cycles
Mechanism to check Relation of Cam with Pendulum
This Motor Reproduces the Motion of Motor "A"
Contacts to Control Loading of Unit
Differential Mechanism to Operate Contacts
Motor "A" Operated from Contacts to Restore Cam to Correct Phase Position with Pendulum every 2 Seconds
Selsyn Motor to Indicate Throttle Position
Selsyn Motor to Indicate Throttle Position
Cam Shaft on Turbine Governor Mechanism
Pendulum makes One Complete Swing every 2 Seconds

Fig. 4. Schematic Drawing to Indicate Operation of Warren Frequency and Load Control Device.

Fig. 4 is a schematic drawing which serves to clarify the operation of this device. Only the principal parts are shown, the dotted lines connecting these being intended to merely indicate that the operation of one depends on the other.

The system frequency is checked by a synchronous-motor-driven cam. The position of the cam, in relation to that of the pendulum, is checked every two seconds (one complete swing of the pendulum). The amount by which the cam is out of phase with the pendulum and, consequently, the amount of correction which must be applied during this two-second interval is a direct measure of the integrated frequency error during this time. Also, as this interval is of such short duration, it is practically a measure of the instantaneous frequency error. Contacts, operated by a motor mechanism, hold the circuit closed for a period which is proportional to the frequency error. These impulses of varying duration are transmitted through a relay device to a motor geared to turn the frame of the synchronous motor driving the cam, the duration of the impulses being such as to advance or retard the cam by the amount which it was out of phase with the pendulum. The amount of additional rotation (positive or negative) which is necessary to keep the cam in phase with the pendulum is a direct measure of the integrated frequency error. This motion is also transmitted to and reproduced in each unit controller where the total amount of the correction is indicated, the value of this integrated frequency error being used as a basis for loading each unit. The total integrated frequency error or time error required to effect automatic control is very small, the maximum in use up to the present time being one second total error to change the load on a machine from no load to full load.

An analogy, using a hypothetical case with manual operation, will serve to explain this action. It should be borne in mind, however, that this is not proposed as an operating practice, and also, that *the time intervals mentioned bear no relation to the time values used with the Warren automatic frequency controller.*

Almost everyone interested in system operation is familiar with the Warren master clock which has been in use on power systems for many years and which serves to indicate the integrated frequency error of a system. This is accomplished by a differential gear system through which a hand on a clock face is driven forward by a pendulum-controlled clock mechanism and backward by means of a synchronous motor connected to the system. With this arrangement of course, the hand will stand still when the frequency is correct and will move forward or backward if the system frequency is fast or slow. The amount of the integrated frequency in seconds can then be determined by the location of the indicating hand. The operator may decide to tolerate a certain maximum error, fast or slow, adjusting his station load to keep within these limits. If he does this, the average frequency will be correct.

As a basis for discussion, the following assumptions will be made:

(*a*). The operator will permit a tolerance of plus or minus five seconds integrated error as indicated by the Warren master clock.

(*b*). The station has ample capacity to take all the load swings required for regulation.

(*c*). All the units in the station are operating at one-half load when the integrated time error as indicated by the master clock is zero.

If no change is made in the governor adjustment and the system load increases, the frequency will be lowered and the integrated error will be shown by the Warren master clock. Let it be further assumed that the operator increases the load on each unit in proportion to the integrated frequency error as indicated by the master clock and at a rate which will require full-load at five-seconds error, *i.e.*, for one-second error he will have 0.6 load; for two-seconds error he will have 0.7 load, etc., until he has full-load with five seconds error. As the load drops off, he will reduce the load on his machines in the same ratio until at one-half load the integrated frequency as shown by the master clock will be zero. Further reduction in system load, of course, would give a fast indication on the master clock and the same procedure would be followed until at no-load the system is five seconds fast. The complete cycle is shown in Table I.

TABLE I

LOAD-ERROR VALUES

Time Error in Seconds	Per Cent Station Load
+5 (Slow)	100
+4	90
+3	80
+2	70
+1	60
0	50
−1	40
−2	30
−3	20
−4	10
−5 (Fast)	0

It is also evident that if two or more stations are equipped with master clocks, the use of this scheme in each station would result in the same percentage load change in each station. If the system conditions are such that if a different percentage of load change is required at the second station this can be obtained by choosing a different time error as basis of loading. For instance, if the second station is two times as large as the first and it is desired to have the kilowatt change in load equally divided between the two stations, the second station may choose a ten-second time error as a basis with the first station operating on the five-second error basis.

Assuming the first station as 20,000 kw. capacity, and the second station as 40,000 kw., the loading would be as shown in Table II.

TABLE II

DIVISION OF LOAD BETWEEN STATIONS

System Load (Kw.)	Station No. 1 (Kw.)	Station No. 2 (Kw.)	Integrated Time Error (Sec.)
60,000	20,000	40,000	10
50,000	20,000	30,000	5
40,000	15,000	25,000	2½
30,000	10,000	20,000	0
20,000	5,000	15,000	−2½
10,000	0	10,000	−5
0	0	0	−10

There are many variations of this scheme which might be used to meet different operating conditions.

The Warren frequency controller operates on this same principle in that the load on the machines and stations is proportioned in accordance with the integrated frequency error. The high precision and accuracy of the pendulum which sets the standard of time, however, permits the use of a very small integrated time error, the actual values in use being plus or minus ⅙ second or plus or minus ⅓ second instead of plus or minus 5 or plus or minus 10 seconds, as mentioned in the comparison to manual operation previously given.

As has been stated, the unit controller provided for each machine is designed to register the integrated frequency error. It is also arranged to register the load on the unit in terms of the gate opening on a water wheel unit or throttle opening on a turbine unit or by a wattmeter device. A differential relation between these two indications limits the load on the various units so that it varies directly with the value of the integrated frequency error.

By this means the load on the different machines in the station can be held to some predetermined division, arrangements being included so that this division can easily be changed by hand. Also by comparing this scheme with the one previously described for manual operation, it will be readily seen that two or more of these devices may be used on the same system and that the ratio of the load changes at the different stations may be determined in advance.

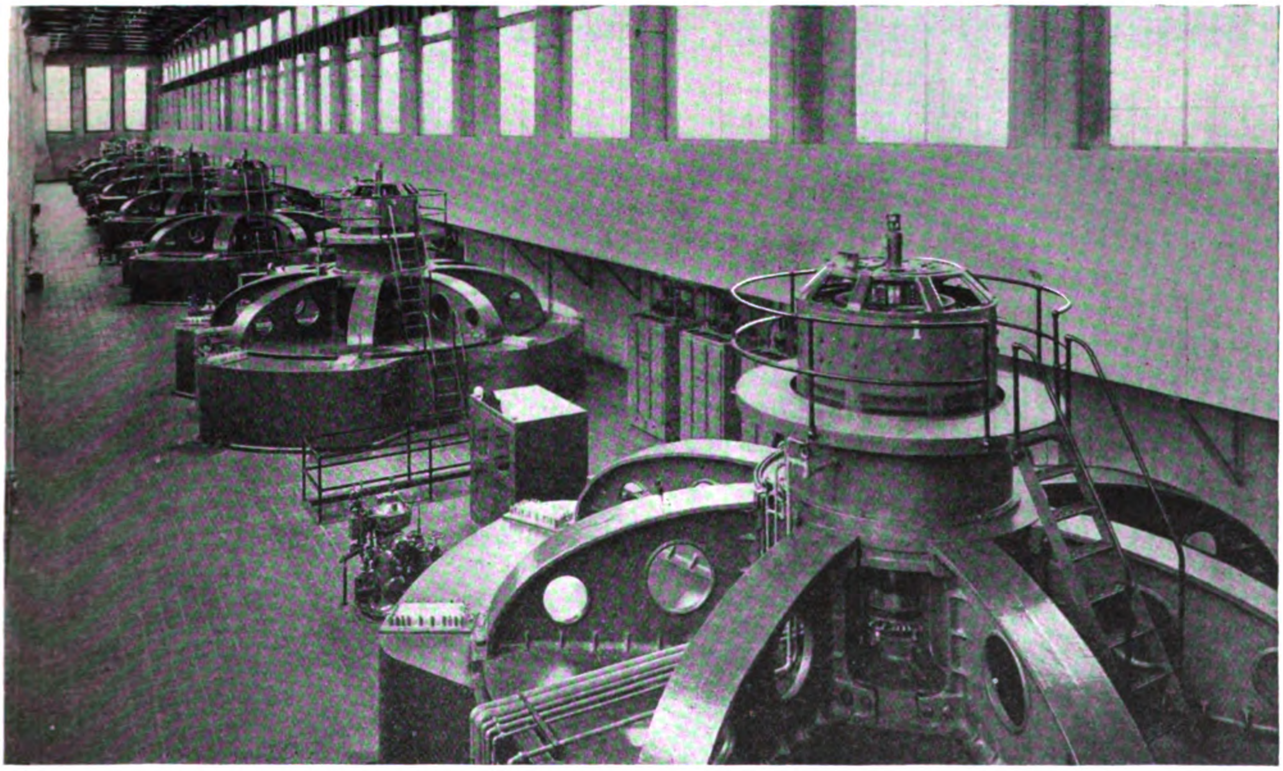
Although the Warren automatic frequency controller operates on the basis of integrated error, the fact that a correction is made, if necessary, every two seconds results in the instantaneous frequency being held within extremely close limits. Also owing to the method of holding load, the average frequency or time-keeping quality of the system is practically exact.

Although the pendulum is an extraordinarily precise instrument, two of these devices may not keep exactly the same time, as difference in temperature, etc., may cause slight variations. A well designed pendulum properly installed should not vary more than one second a day, *i.e.*, a change in the order of $\frac{1}{100,000}$. It is recognized that even this amount of error will affect the operation when two of these automatic devices are operating on the same system. The rate of load shift due to this cause, however, is easily calculated for any given error; and the rate of load shift is so slow that corrections do not place any onerous burden on the operation. For instance, with the control equipment designed to cause the load on the station to increase from no-load to full-load with one-second integrated error, a difference of one second per day in the timing of the pendulums would cause a transfer of load at the rate of full-load in a 24-hr. period.

A developmental installation has been in operation in a hydroelectric plant for several months, controlling three water-wheel generators of 15,000-kw. capacity each. A second installation has been placed in a steam plant and controls three 35,000-kw. turbine units. The stations in which these equipments are installed are at times connected together. The operation of these two installations has been all that could be expected, either when operating singly or with both automatic devices operating on the same system.

As power systems increase in size and as interconnection between systems becomes more common, the need for such a device becomes more pronounced as it will be necessary for more than one station to share the load swings, *i.e.*, the regulation of frequency must be done at a number of points; and a device to accomplish this must not only be of very high precision, but must also be so designed that the slight inaccuracies which are necessarily present will not prevent the successful simultaneous operation of any number of the automatic devices.

Eight Units in the Largest Automatic Hydroelectric Station



These 12,500-kv-a. generators, ten of which will constitute the ultimate installation in the Ohio Falls Hydro Station of the Louisville Gas and Electric Company, embody new features of design and control which place this station among the most noteworthy of the present day

The Influence of Experience on the Design of the Steam Turbine

By ERNEST L. ROBINSON

Turbine Engineering Department, General Electric Company

DURING the last quarter of a century the steam turbine, as developed by the General Electric Company, has grown from 5000 kilowatts—the maximum capacity of an individual unit in 1903—to 208,000 kilowatts in a triple-cross-compound unit in 1928.

Single-cylinder turbines are still increasing in size, but the remarkable growth that has taken place in recent years is due to compounding. Diversity of type and variation in application are always increasing, and at the same time marked improvements in detail are being constantly introduced. These changes are continually leading to the production of machines more efficient in performance and more dependable in operation.

During this period of 25 years the Company has manufactured steam turbines with a total capacity of 20,000,000 kilowatts. This figure includes machines made for the generation of electric power, and excludes those for mechanical drive and the propulsion of ships. There are 154 machines of 30,000 kw. or larger which aggregate more than 5,500,000 kilowatts of this huge total—the average capacity of these 154 machines being over 36,000 kilowatts each; and they have already been in service (on the average) for a period exceeding five years. Again, 24 machines of 50,000 kilowatts, or larger, account for more than 1,500,000 kilowatts—the average being over 64,000 kilowatts; and these have already seen an average period of service exceeding two years. Fourteen single-casing machines, ranging from 50,000 to 75,000 kilowatts and averaging 55,000 kilowatts each, have been in service for an average of over two years.

It is the purpose of this article to direct attention to the vast accumulation of experience gained during this development and to show how it has not only played a determining part in the design of turbines now being manufactured, but also how the degree of advancement which now characterizes the art could not have been obtained except through such experience.

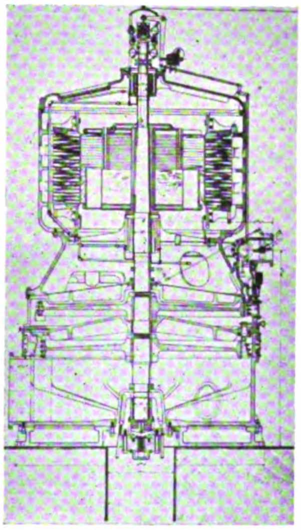


Fig. 1. 1903
5000 kw., 500 r.p.m., 2 Stages

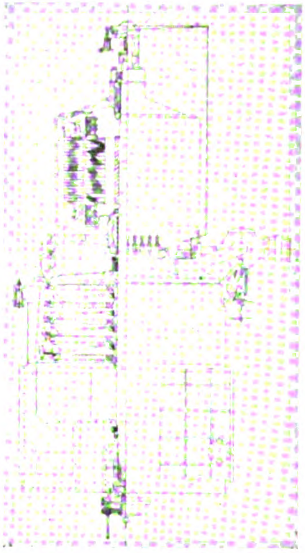


Fig. 2. 1908
14,000 kw., 750 r.p.m., 5 Stages

In the evolution of any art there are two distinct periods of growth, *first* a period of *creation* and successful application; and *second* a period of progressive *development* toward perfection.

During the first period the patrons of the art, in this case the purchasers of turbines, accepted the new apparatus because of its obvious superiority to the equipment standard at that time. The invention had been successfully applied and this success was evidenced by the large bulk of applications showing that the advantages of the new machine were appreciated by the public. Its general proportions had been made in accord with fundamental theory, although with little knowledge of refinements. In this theory lay its utility and economic advantages as compared with reciprocating engines. The economy of floor space, the ability to make use of a high vacuum and the corresponding benefits in improved steam cycle, were of such importance in comparison with the equipment previously used that, during the early stages of the art, refinements of design impossible at that time were really of very little economic signifinance. However, the success of the General Electric steam turbine during this period of inventive creation, and the large number of machines manufactured and placed in operation, were to become of extreme importance as providing a reservoir of experimental information for use during the later period of development. In this connection it is well to recall that the one kind of experiment, the results of which are absolutely true and must be heeded, is the test of actual service in the owner's possession.

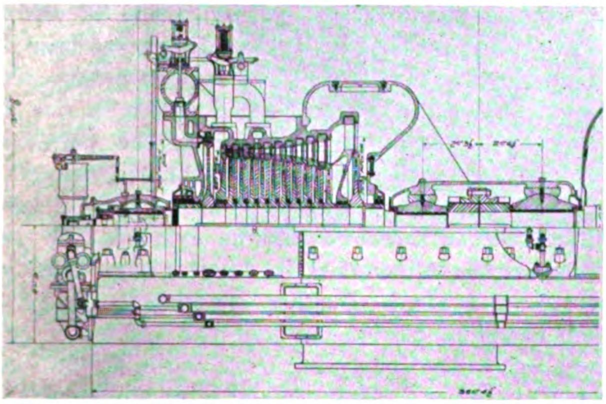


Fig. 3. 1913
12,500 kw., 1500 r.p.m., 12 Stages

Fig. 1 shows the assembly of the "mammoth" 5000-kw. 500-r.p.m. 2-stage vertical steam turbine installed at the Fisk Street Station of the Commonwealth Edison Company in Chicago in 1903. Five years later, that is to say in 1908, this type of turbine had grown so that the machine illustrated in Fig. 2, rated 14,000 kw., 750 r.p.m., 5 stage, was placed in service. It should be noted that the 2-stage design, with 4 rows of moving buckets on each stage, has given way to a 5-stage design with only two rows of moving buckets on each stage. While the total number of rows of buckets is nearly the same, the 1908 arrangement was more efficient than that of 1903. Each one satisfied the theory. The five years' development had shown some improvement, but there was a large difference between the steam path of that time and the path adopted during the ten years following.

In 1908 the first commercial designs were placed in manufacture for the horizontal turbines, and by 1913 this type of machine had reached the point of development illustrated in Fig. 3, which represents a 12,500-kw. 1500-r.p.m. 12-stage turbine as manufactured for the Lehigh Navigation Company. Comparing this with Figs. 1 and 2, there are three more rows of moving buckets but only one wheel has more than a single row. This arrangement is as suitable with respect to the theory as the two previous schemes, but is of as revolutionary significance with reference to the efficient performance of the turbine as was the change from a vertical to a horizontal shaft with reference to the mechanical characteristics of the turbine.

The three turbines illustrated in these three pictures, covering a period of 10 years from 1903 to 1913, may be considered as representative of the first period of the art. The last design, while strikingly different in detail from modern turbines is astonishingly like them in the general arrangement of the steam path. The three machines were all capable of taking advantage of those theoretical qualities which set the steam turbine on a plane distinctly above the reciprocating engine. During the 10 years concerned, a type was arrived at which was to persist throughout the later period of *development*.

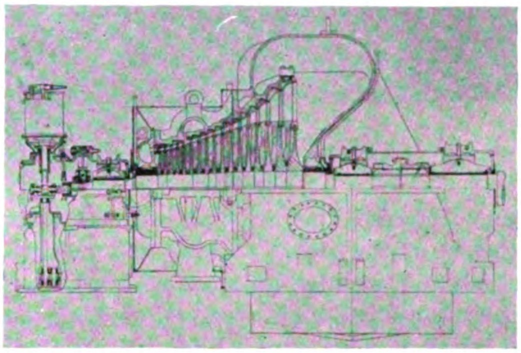


Fig. 4. 1918
30,000 kw., 1800 r.p.m., 17 Stages

The second period in the evolution of an industrial art, which is thought of as the period of development, really covers the period of real achievement. During this time the industry becomes competitive and the theoretical aspects become ancient history. The advantages of the theory have disappeared simply by becoming common. It is in this period that industrial success can be attained only through refinement and perfection, or what is called mechanical "development." Originally the turbine worked and was good, but in the later period anybody could make it, and make it good enough to benefit by its features of superiority over a reciprocating engine.

Fig. 4 represents a 30,000-kw. 1800 r.p.m. 17-stage turbine as manufactured in 1918. While by no means a machine of maximum size, this turbine approaches modern proportions and has a mechanical efficiency which is reasonably good at the present time, although the steam cycle used had not yet gone through its modern developments.

During the past ten years has come about the real understanding of the things essential to the unfailing mechanical efficiency and reliability of the turbine. Little details are not charted by theory, but their significance is learned in the practice of the art and frequently makes all the difference between continuous availability for service with certainty of efficient performance, and annoying shutdowns for repairs or rebuilding to improve efficiency.

The design of the disk wheel was originally brought to perfection in accordance with the theory that stresses should be uniform, but after many hundreds had been in service for years certain troubles occurred. Tests and examination of service records showed that vibration resonance should be avoided by certain margins of speed. This principle was not inherent in the theory of the steam turbine and machines had been built and operated for years without regard to it. However, until the facts were appreciated an occasional wheel was by chance likely to get in trouble. Such wheels have since been removed from service; but the important thing to note is that it was not enough to add this principle to the theory of the turbine, but that the breadth of margins for suitable protection had to be worked out by painstaking analysis of records of service, using methods such as are used by the actuary in assuring protection from an insurance risk. In such a process a large bulk of data is a prime requisite of reliable results.

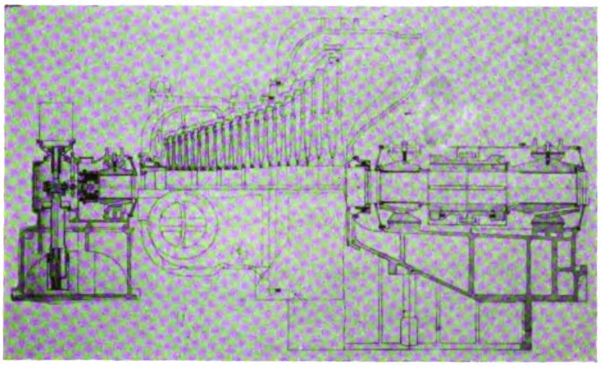


Fig. 5. 1923
50,000 kw., 1200 r.p.m., 21 Stages

During this period of development or perfection of the art, success during the first period is of necessarily great significance in providing the required bulk of data. A manufacturer who has had marked success during the early stages of an art when refinements were not of great importance is in a peculiarly fortunate position later on when the time comes that refinements are all important; because the early success has provided the experience necessary for sound and rapid development. In this age of industrial expansion it is difficult for any manufacturer to get a "corner on brains" and brains are necessary both for inventive creation and for subsequent development. But in the latter case something else is also a prime requisite, namely, the previous experience without which the technical brains have no foothold on which to stand.

Modern science and modern engineering begin first with facts. The abstract facts of theory give birth to the design. The real facts of experience, and experience only, can lead to perfection.

Again referring to the earlier period of growth, certain fairly obvious features of design had been recognized as affecting the mechanical efficiency of the turbine. Later, when units had grown in size and types were becoming standardized, the perplexing situation arose that different machines intended to have the same efficiency showed appreciably different efficiencies. It therefore became evident that there were certain refinements in detail design that had yet to be studied. Further experiments and tests were therefore carried out and the inferences from these led to the incorporation of various features in actual turbines. After the lapse of sufficient time for service and tests it finally became possible to give definite assurance that the procedure had resulted in the production of turbines that would give a uniformly good performance.

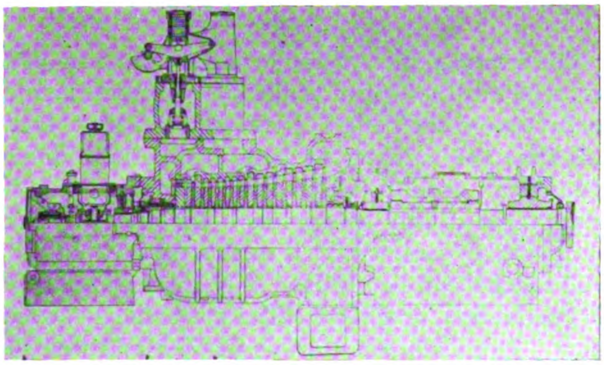


Fig. 6. 1928
High-pressure Cylinder, 53,000 kw., 1800 r.p.m., 17 Stages

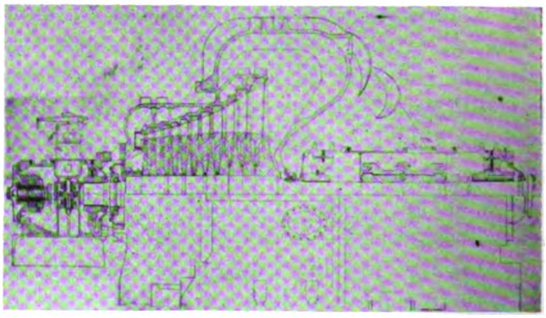


Fig. 7. 1928
Low-pressure Cylinder, 56,000 kw., 1800 r.p.m., 12 Stages

165,000-kw., 29-stage Compound-unit Comprising One High-pressure Cylinder and Two Low-pressure Cylinders

Fig. 5 represents a 50,000-kw. 1200-r.p.m. 21-stage turbine designed in 1923. The turbine art is a dynamic art. The past ten years has shown the necessity for the adaptability of the turbine to the many different steam cycles in use at the present time. Under such circumstances it is hardly appropriate to speak of perfection, but it is clear that not only must the theory be sound but the practice must rest on fundamental grounds.

One of the significant tendencies of the art of late years has been the necessity for utilizing the materials so as to make possible turbines of larger and larger ratings with better efficiencies and economical costs. Great skill has been required in order to accomplish these results without prejudice to our standards.

During this period some difficulties were encountered with buckets in various locations of the machine. In investigating these matters, theoretical circumstances were thoroughly gone over and stresses were found to be very low. Every known precept of the art was satisfied, but the results of experience with hundreds of turbines had shown a small percentage of trouble. Even a small percentage of trouble is not tolerable in a well developed machine, and it thus became necessary to find out the facts and establish a new theory to suit the facts.

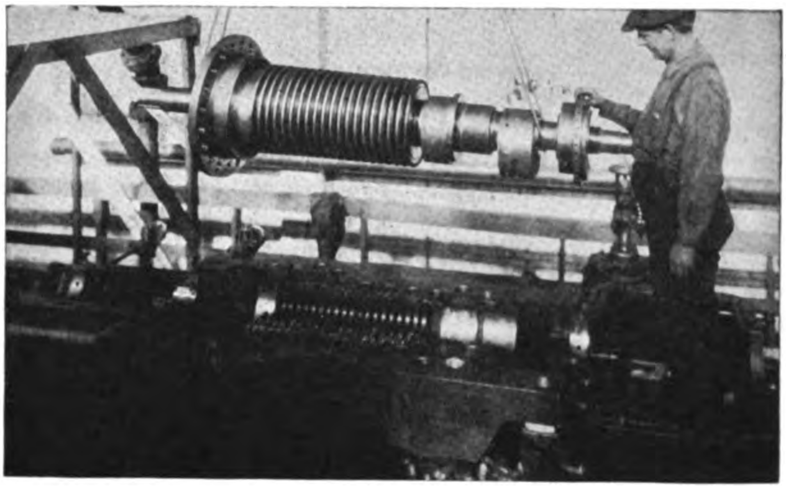


Fig. 8. Turbine Rotor for 1200 lb. Pressure

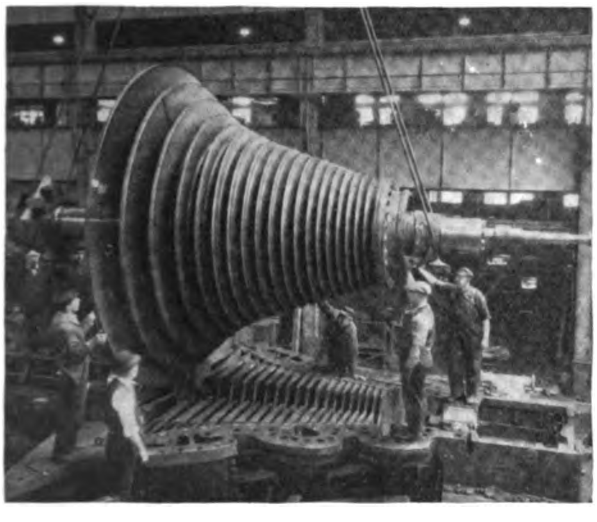


Fig. 9. Assembling 60,000-kw. Single-cylinder Turbine

The records covering literally ten thousand wheel-years of service were thoroughly gone over and the results carefully charted. Paralleling this analysis, tests of an analytical nature were made in the factory. Charts of service record showed a certain well defined relation between the conditions of service and the chances of a bucket getting into trouble. The theory evolved to suit this evidence was borne out by the experiments in the factory. The coefficients whereby this theory could be applied were made from the service records of the machines. Again it was interesting to have theory, but the theory was worthless without the bulk of successful experience in machines designed without reference to this theory, the records of which were used to establish the necessary coefficients. The result was the modern buckets designed for maximum reliability under modern conditions of service.

Figs. 6 and 7 show the high-pressure and one of the two duplicate low-pressure elements of the 165,000-kw. turbine recently placed in service for the American Gas & Electric Company. This is typical of a large size unit and represents the result of 25 years of growth as compared with the 5000-kw. unit illustrated in Fig. 1. This cross-compound unit in three elements is designed for resuperheating and the full benefit of the steam extraction cycle.

Fig. 8 shows the rotor of a 1200-lb. turbine. A comparison of this with Fig. 9, which shows the rotor of a single-cylinder 60,000-kw. turbine for standard pressures, illustrates the wide range of conditions which must be met in the design of modern turbines, and emphasizes the need for fundamental knowledge based on long and wide experience combined with an understanding of the principles involved and a recognition of the necessity of constantly revising that understanding along the lines dictated by experience.

Grounding the Neutral Through Resistance or Reactance

Reasons for Grounding the Neutral—Purpose of Using Resistance or Reactance in Ground Connection—Analysis of Maximum Permissible Resistance—Advantages of Using Reactance

By W. W. LEWIS
Central Station Engineering Department, General Electric Company

AMERICAN practice in grounding the neutral may in general be summarized as follows:

On systems which are fed at generator voltage, the neutral is grounded solidly or through a small value of resistance (zero to 10 ohms). (1) In some cases reactance is used in the neutral in place of resistance.

Of systems which are fed at higher than generator voltage (through step-up transformers), the majority are grounded solidly. Those which are grounded through resistance have a comparatively high resistance (10 to 150 ohms). (1)

Some systems in each class are operated with the neutral not grounded.

The purposes of grounding the neutral are:

(1). To reduce voltage strains on the system and apparatus. This is especially important on cable systems, where the insulation of the cable may be limited by the dimensions of the cable ducts.

(2). To assist in relaying by giving positive and dependable short circuits when one conductor becomes grounded.

In recent years the matter of power stability of systems has received much attention. (2) In order to increase stability there is a tendency to consider placing impedance in the neutral. This reduces the current on line-to-ground short circuits, which are the most common cause of instability.

Also, on some systems the short-circuit currents have become exceedingly great, much greater in fact than is necessary for successful relaying. The duty on oil circuit breakers in many cases has thus outgrown the capacity of the breakers. For this reason, also, impedance in the neutral is receiving consideration.

The voltage strain that is reduced by grounding the neutral is that due to an arcing ground. Theoretically the maximum voltage that can be produced by an arcing ground on an isolated neutral system is 7.5 times the peak value of the line-to-neutral voltage. (3) This stress occurs on the two ungrounded phases of a three-phase system. On account of the natural damping in a system, the value of 7.5 times normal can never be obtained and the probable maximum is from 5 to 5.5 times normal. Some investigators by a different method of analysis arrive at a somewhat lower maximum. (4)

If the neutral is grounded solidly (zero resistance) there can be no oscillation and no voltage rise can occur.

If the neutral is grounded through resistance, oscillation may occur but it will be only slightly cumulative for the charge on the ungrounded conductors will be drawn off through the neutral ground connection. The probable maximum voltage rise of the two ungrounded conductors, with values of resistance considered suitable for neutral grounding, will be in the neighborhood of 2.5 times normal. Low resistance will approach the solidly grounded neutral state and high resistance the isolated neutral state. These values are summarized in Table I.

TABLE I

MAXIMUM VOLTAGE DUE TO ARCING GROUND

	Number of Times Crest Value of Line-to-neutral Voltage
Initial arc	2.5
Final arc	
(*a*). No damping considered	7.5
(*b*). Damping considered	5.7
(*c*). Damping and capacitance between lines considered	5.5
With neutral grounded through resistance (not greater than the critical value)	2.5
With neutral grounded solidly	1.0

Maximum Permissible Resistance in Neutral

The question arises as to how much resistance is permissible in the neutral and still not produce dangerous oscillations. The writer proposes the following criterion for determining the maximum permissible resistance.

Fig. 1 illustrates the flow of charging current in a three-phase overhead system when one conductor is grounded and the neutral is isolated.(6) The normal three-phase charging current is I_n. Now if the neutral is grounded, a short-circuit current flows as shown in Fig. 2, in addition to the charging currents shown in Fig. 1. The actual flow is a combination of those in Figs. 1 and 2. Vectorially, these currents may be somewhat as shown in Fig. 3.

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(1) "Present Day Practices in Grounding Transmission Systems," Report of Subcommittee on Grounding, of Protective Devices Committee, *Trans. A.I.E.E.*, 1923.

(2) "Fundamental Considerations of Power Limits of Transmission Systems," by R. E. Doherty and H. H. Dewey, *Trans. A.I.E.E.* 1925; also "Transmission Stability," by C. L. Fortesque, *Trans. A.I.E.E.*, 1925.

(3) Analysis by J. E. Clem based on theory of Dr. Petersen. (See "The Intermittent Grounding Effect," by W. Petersen, *Elektrotechnische Zeitschrift*, Nov. 22 and 29, 1917.)

(4) "Voltages Induced by Arcing Grounds," by Peters and Slepian *Trans A.I.E.E.*, 1923.

In a solidly grounded neutral overhead system, I_c (charging current at fault) equals approximately 0.75 I_n. With neutral grounded through resistance, I_c lies between 0.75 I_n and 1.5 I_n. In a three-core cable system, I_c varies approximately from 0.75 I_n to 1.73 I_n; and in a single-core cable system (or one with three conductors and individual ground sheaths surrounding each conductor), I_c varies approximately from I_n to 3 I_n.

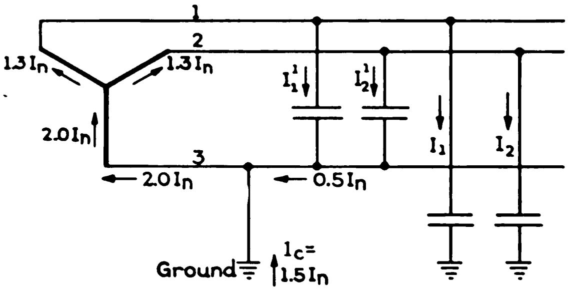

Fig. 1. Flow of Current with One Conductor Grounded. Current values expressed in terms of normal three-phase charging current

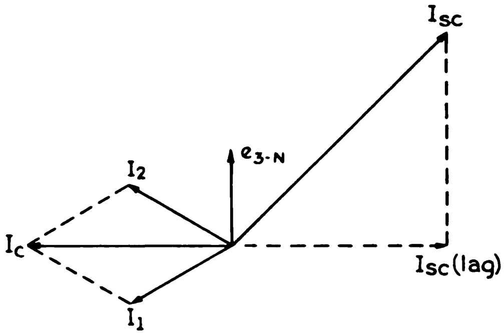

Fig. 3. Relation of Charging Current at Arc on Phase 3, and Short-circuit Current at Same Point When Neutral is Grounded Through Resistance (Fig. 2)

In the case of the neutral grounded through resistance, the current will be predominantly lagging if the resistance R is small, or more nearly in phase with the line-to-neutral voltage of the short-circuited leg if R is large. The resistance R should be so chosen that the lagging component of I_{sc} is always equal to or greater than I_c at the fault. In such cases there can be no arcing grounds and no serious voltage oscillations. The ungrounded lines may be stressed to 2.5 times normal voltage to ground, but this is not serious in normally insulated apparatus.

The following general equation for determining the limiting permissible resistance in accordance with the previous considerations has been developed by Miss Edith Clarke:

$$R = 10\,\frac{kv.^2}{kv\text{-}a.}\sqrt{\frac{x - x^2\left(\dfrac{\sqrt{3}}{100}\,\dfrac{kv.}{kv\text{-}a.}\,I_c\right)}{\dfrac{\sqrt{3}}{100}\,\dfrac{kv.}{kv\text{-}a.}\,I_c}} \qquad (1)$$

in which

R = neutral resistance in ohms
$kv.$ = line-to-line kilovolts
$kv\text{-}a.$ = generating kv-a. on which reactance is based

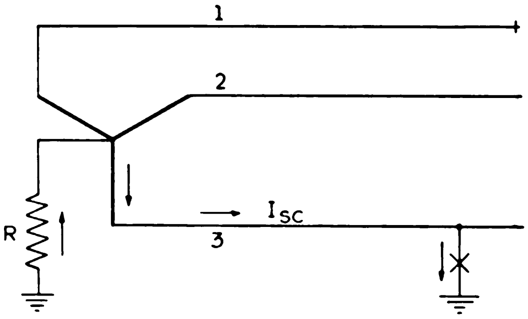

Fig. 2. Three-phase System with Resistor Between Neutral and Ground. Flow of short-circuit current with ground on Phase 3

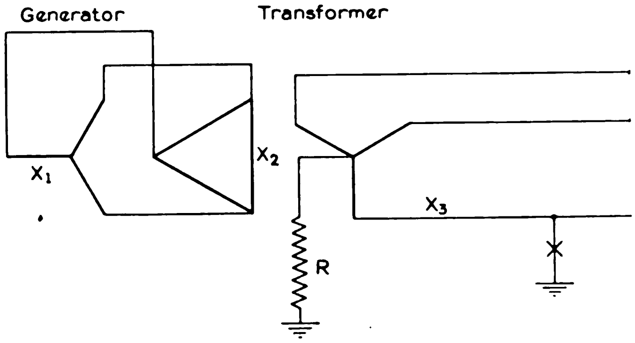

Fig. 4. Assumed System Set-up for Short-circuit Calculation for Systems Over 15,000 Volts

x = system reactance to point of fault expressed in per cent
I_c = charging current in ground at fault

Example 1

Assume a 100-mile 66-kv. network with 250,000-cir. mil conductors spaced six feet apart triangularly.

The normal charging current at 60 cycles is 23.2 amp. for 100 miles. Assume that the charging current in the ground at the fault I_c equals 1.5 times normal charging current, or 34.8 amp. Assume that the generating capacity is 100,000 kv-a. in turbine-generators with 25 per cent reactance, and that the step-up transformers have 10 per cent reactance (Fig. 4). The transmission network reactance to the point of fault is 15 per cent based on 100,000 kv-a.

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(6) "The Neutral Grounding Reactor," by W. W. Lewis, *Trans. A.I.E.E.*, 1923.

Then by methods previously explained[6] equations may be written for the positive, negative, and zero phase sequence reactance as follows:

$$
\begin{aligned}
Z_1 &= j\,(x_1+x_2+x_3)\\
Z_2 &= j\,(0.73\,x_1+x_2+x_3)\\
Z_0 &= 3\,R+j\,(x_2+4\,x_3)\\
Z &= Z_1+Z_2+Z_0\\
&= 3\,R+j\,(1.73\,x_1+3\,x_2+6\,x_3)
\end{aligned}
$$

$$I_{sc}=\frac{3\times 100\,I_n}{Z}=\frac{100\,I_n}{R+j\,(0.577\,x_1+x_2+2\,x_3)} \qquad (2)$$

Case 1

Let $x_1 = 25$ per cent on 100,000 kv-a. basis
$x_2 = 10$ per cent
$x_3 = 15$ per cent
$x = 0.577\times 25+10+2\times 15 = 54.4$ per cent

Then from Equation (1)

$$R=\frac{10\times 66^2}{100{,}000}\sqrt{\frac{54.4-54.4^2\left(\frac{\sqrt{3}}{100}\;\frac{66\times 34.8}{100{,}000}\right)}{\frac{\sqrt{3}}{100}\;\frac{66\times 34.8}{100{,}000}}}$$

$= 159.5$ ohms

Case 2

Let $x_1 = 25$ per cent
$x_2 = 10$ per cent
$x_3 = 0$ per cent
Then $x = 24.4$ per cent

$$R=\frac{10\times 66^2}{100{,}000}\sqrt{\frac{24.4-24.4^2\left(\frac{\sqrt{3}}{100}\;\frac{66\times 34.8}{100{,}000}\right)}{\frac{\sqrt{3}}{100}\;\frac{66\times 34.8}{100{,}000}}}$$

$= 108$ ohms

As a check, the ohms resistance may be reduced to the per cent resistance based on 100,000 kv-a. at 66,000 volts.

For Case 1: 159.5 ohms = 367 per cent

$$I_{sc}=\frac{100\times 875}{367+54.4\,j}=\frac{100\times 875}{370}=236 \text{ amp.}$$

The lagging component of $I_{sc}=\frac{54.4}{370}\times 236 = 34.6$ amp., which is approximately the assumed charging current at the fault.

For Case 2: 108 ohms = 248 per cent

$$I_{sc}=\frac{100\times 875}{248+24.4\,j}=\frac{100\times 875}{249}=352 \text{ amp.}$$

The lagging component of $I_{sc}=\frac{24.4}{249}\times 352 = 34.5$ amp., which is approximately the assumed charging current at the fault.

From this calculation it is apparent that with the simple set-up assumed the value of resistance obtained for a short circuit just outside of the station ($x_3=0$) should be considered the maximum permissible value. In more complicated set-ups, it may be necessary to make calculations for short circuits at various parts of the system and then to select the minimum value as the maximum permissible value to be used.

For a sustained short circuit, the lagging component will be larger than the lagging component of the instantaneous short-circuit current, as may be seen from the following example:

Example 2

Instantaneous Short Circuit

Let $x = 15$ per cent
$R = 85$ per cent
$I_n = 2000$ amp.

$$I_{sc}=\frac{100\times 2000}{85+15\,j}=2320 \text{ amp.}$$

$$I_{sc}\,(\text{lag})=\frac{15}{86}\times 2320 = 405 \text{ amp.}$$

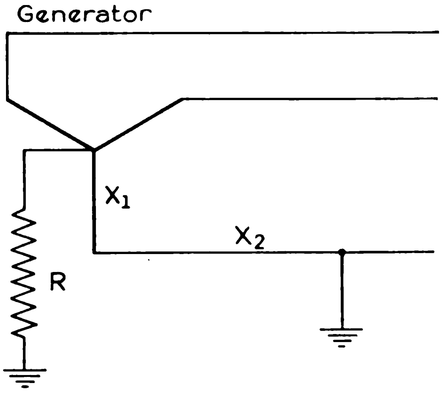

Fig. 5. Assumed System Set-up for Short-circuit Calculation for Systems up to and Including 15,000 Volts

Sustained Short Circuit

Let $x = 100$ per cent
$R = 85$ per cent

$$I_{sc}=\frac{100\times 2000}{85+100\,j}=1530 \text{ amp.}$$

$$I_{sc}\,(\text{lag})=\frac{100}{131}\times 1530 = 1170 \text{ amp.}$$

It is therefore on the safe side to use the instantaneous short-circuit condition for calculating the neutral resistance.

In order to give an idea of the approximate maximum permissible resistance for systems of different voltage, sets of curves have been drawn up for underground cables and for overhead lines.

Underground Cables

Table II shows the insulation for standard three-conductor cables, the calculated capacitance, and the charging current. In Fig. 6 are plotted values of the charging current I_c for 100 miles of cable against kilovolts. (I_c is assumed to be 1.73 times the normal

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(6) "Calculation of Single-phase Short Circuits by the Method of Symmetrical Components," by A. P. Mackerras, GENERAL ELECTRIC REVIEW, April and June, 1926.

charging current). From this curve the equation of the charging current at the fault is derived:

$$I_c = (86+10.5 \text{ kv.}) \frac{\text{length}}{100} \tag{3}$$

For voltages up to and including 15,000 volts, it is assumed that power is fed directly without transformation (Fig. 5). Then for instantaneous short circuits (assuming the system fed by turbine-generators):

$$Z_1 = j\,(x_1+x_2)$$
$$Z_2 = j\,(0.73\,x_1+x_2)$$
$$Z_0 = 3\,R+j\,(0.27\,x_1+3\,x_2)$$
$$I_{sc} = \frac{100\,I_n}{R+j\left(\frac{2}{3}\,x_1+\frac{5}{3}\,x_2\right)}$$

If $x_2 = 0$

$$I_{sc} = \frac{100\,I_n}{R+\frac{2}{3}\,jx_1}$$

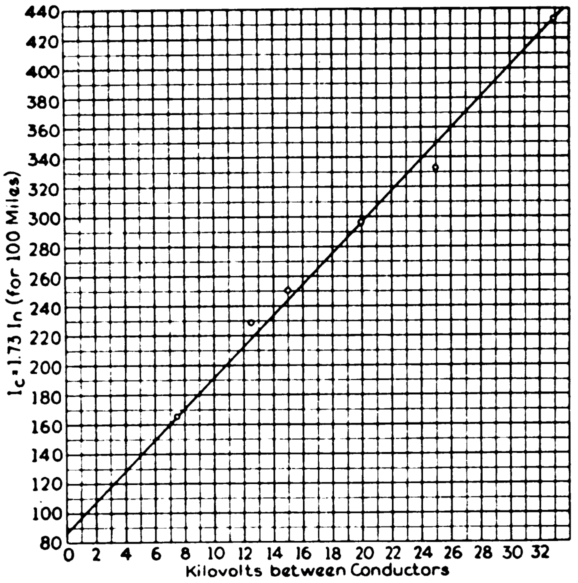


Fig. 6. Charging Current to Ground of Underground Cables 7.5 to 33 kv. with One Conductor Grounded

$$I_c = (86+10.5 \text{ kv.}) \frac{\text{Length}}{100}$$

Assume further that all cable systems are fed by turbine-generators with instantaneous reactance equal to 15 per cent.

Then

$$I_{sc} = \frac{100\,I_n}{R+j\,10} \tag{4}$$

For voltages over 15,000 volts, assume that power is fed through transformers (Fig. 4).

Then

$$I_{sc} = \frac{100\,I_n}{R+j\left(0.577\,x_1+x_2+\frac{5}{3}\,x_3\right)}$$

If $x_3 = 0$

$$I_{sc} = \frac{100\,I_n}{R+j\,(0.577\,x_1+x_2)}$$

Let $x_1 = 15$ per cent
$x_2 = 6$ per cent

Then

$$I_{sc} = \frac{100\,I_n}{R+15\,j} \tag{5}$$

For plotting, Equation (1) may be rearranged as follows, with I_c replaced by its equivalent from Equation (3):

$$R' = n\,R = \frac{kv.^2}{10{,}000}\sqrt{\frac{x - x^2\,\frac{\sqrt{3}}{100}\,\frac{kv.}{100{,}000}\,(86+10.5\,kv.)\,F}{\frac{\sqrt{3}}{100}\,\frac{kv.}{100{,}000}\,(86+10.5\,kv.)\,F}} \tag{6}$$

in which

R = neutral resistance in ohms
$kv.$ = line-to-line kilovolts
x = system reactance to point of fault expressed in per cent
$n = \frac{kv\text{-}a.}{100{,}000}$
$l = \frac{\text{length}}{100}$
$F = \frac{l}{n}$

TABLE II

STANDARD THREE-CONDUCTOR PAPER-INSULATED CABLE (CIRCULAR CONDUCTOR)

Rated Voltage	Operating Voltage	Size Conductor	Most Used Size Cond.	Spacing Between Conductors (Inches)	COND. TO GROUND (INCHES)		Capacity to Neutral	Amp. Charging Current Per Mile at 60 Cycles	Charging Current 100 Miles	1.73 × Amp. Charging Current 100 Miles
					Solid Neutral	Isolated Neutral				
7,500	6,600	2/0–500,000	250,000	0.2	0.15	0.20	0.587	0.955	95.5	165
12,500	11,000–12,000	2/0–500,000	250,000	0.29	0.22	0.29	0.483	1.32	132.	228
15,000	13,200–13,800	2/0–500,000	250,000	0.33	0.25	0.33	0.441	1.44	144.	250
20,000	18,000	2/0–500,000	250,000	0.42	0.315	0.42	0.392	1.71	171.	296
25,000	22,000–24,000	2/0–350,000	250,000	0.52	0.39	0.52	0.354	1.92	192.	332
33,000	26,400–27,500	350,000	350,000	0.625	0.47	0.625	0.348	2.5	250.	433

Values for capacitance and charging current based on cable insulated for isolated neutral.
Cable for solidly-grounded neutral has approximately 15 per cent greater charging current than cable for isolated neutral.
Sector cable has approximately 5 per cent greater charging current than has round-conductor cable.

The values of reactance in Equations (4) and (5) may now be substituted in Equation (6) and values of R' may be calculated for the various voltages.

In Fig. 7 are plotted values of R' equal to $n\ R$ as ordinates against F as abscissas for 7.5, 12.5, 15, 20, 25, and 33 kv.

For 45 and 66 kv., single-core cable is used. The assumed dimensions of this cable are as follows:

45-kv. cable: Radius of conductor, 0.41 in.; inner radius of sheath, 0.93 in.

66-kv. cable: Radius of conductor, 0.5 in.; inner radius of sheath, 1.25 in.

Table III shows the calculated capacitance and charging current of the 45 and 66-kv. cables. The charging current, I_c equals three times normal charging current and is plotted in Fig. 8; and the values of R' equal to $n\ R$ are plotted in Fig. 9.

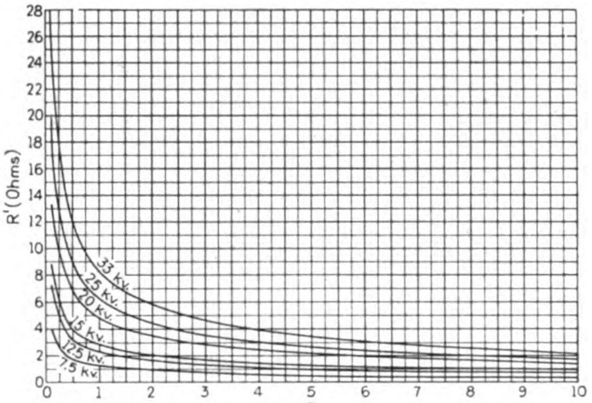


Fig. 7. Permissible Resistance for Underground Cables 7.5 to 33 kv.

$$F = \frac{\text{Length}}{100} \times \frac{100{,}000}{kv\text{-}a.}$$

$$\text{Res.} = R' \times \frac{100{,}000}{kv\text{-}a.}$$

Overhead Lines

Table IV gives data on overhead lines for the standard voltages, together with capacitance and charging current for assumed spacing and size of conductors.

In Fig. 10 are plotted $I_c = 1.5$ times normal charging current for 100 miles against kilovolts. The equation of this straight-line curve is:

$$I_c = (6 + 0.44\ kv.)\ \frac{\text{length}}{100} \tag{7}$$

TABLE III

Capacitance and Charging Current of 45 and 66-kv. Single-conductor Underground Cables

Rated Voltage	Capacity to Neutral (Mf. per mile)	Amp. Charging Current Per Mile at 60 Cycles	Charging Current 100 Miles	Three Times Amp. Charging Current 100 Miles
45000	0.438	4.29	429	1287
66000	0.391	5.61	561	1683

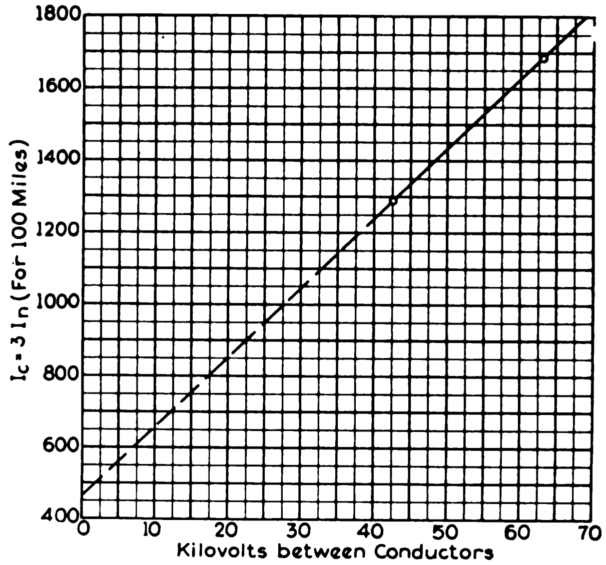


Fig. 8. Charging Current to Ground of Underground Cables 45 and 66 kv. with one Conductor Grounded

$$I_c = (460 + 19.5\ kv.)\ \frac{\text{Length}}{100}$$

Equation (1) may now be rearranged as follows:

$$R' = n\ R = \frac{kv.^2}{10{,}000}\sqrt{\frac{x - x^2\,\frac{\sqrt{3}}{100}\ \frac{kv.}{100{,}000}\,(6+0.44\ kv.)\ F}{\frac{\sqrt{3}}{100}\ \frac{kv.}{100{,}000}\,(6+0.44\ kv.)\ F}} \tag{8}$$

TABLE IV

CAPACITANCE AND CHARGING CURRENT OF OVERHEAD LINES (THREE-PHASE)

Rated Voltage	Assumed Size Conductor (Cir. mil.)	Diameter of Conductor (Inches)	Spacing (Feet)	Capacitance Per Mile (Microfarads)	Charging Current (Amp. per Mile)	Amp. for 100 Miles	1.5 × Amp. per 100 Miles
33,000	250,000	0.575	3	0.0186	0.1335	13.35	20.0
44,000	250,000	0.575	4	0.0174	0.167	16.7	25.1
66,000	250,000	0.575	6	0.0162	0.232	23.2	34.8
88,000	250,000	0.575	8	0.0153	0.293	29.3	44.0
110,000	250,000	0.575	10	0.0148	0.370	37.0	55.5
132,000	250,000	0.575	13	0.0142	0.406	40.6	60.9
154,000	400,000	0.728	15	0.0144	0.484	48.4	72.6

in which the symbols have the same meaning as in Equation (6).

Assume the connections to be as in Fig. 4, and that all overhead systems are fed by waterwheel generators.

Then

$$Z_1 = j\ (x_1 + x_2 + x_3)$$
$$Z_2 = j\ (1.25\ x_1 + x_2 + x_3)$$
$$Z_0 = 3\ R + j\ (x_2 + 4\ x_3)$$
$$Z\ = 3\ R + j\ (2.25\ x_1 + 3\ x_2 + 6\ x_3)$$
$$I_{sc} = \frac{100\ I_n}{R + j\ (0.75\ x_1 + x_2 + 2\ x_3)}$$

Assume

$x_1 = 20$ per cent
$x_2 = 10$ per cent
$x_3 =\ 0$ per cent

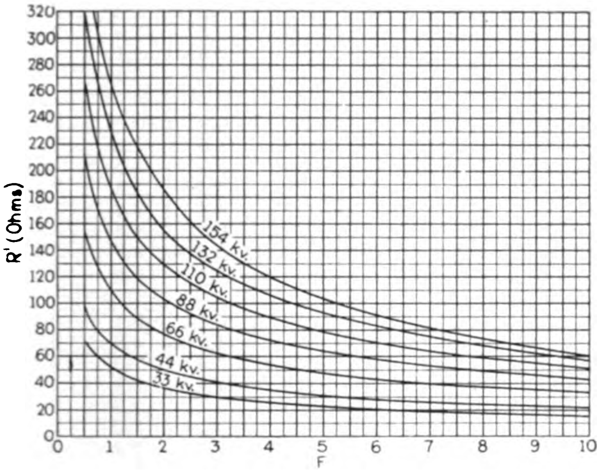


Fig. 9. Permissible Resistance for Undergrounded Cables 45 and 66 kv.

$$F = \frac{\text{Length}}{100} \times \frac{100{,}000}{kv\text{-}a.}$$
$$\text{Res.} = R' \times \frac{100{,}000}{kv\text{-}a.}$$

Then

$$I_{sc} = \frac{100\ I_n}{R + 25\ j} \tag{9}$$

Placing $x = 25$ in Equation (8) the values of R' for the various voltages may be calculated.

In Fig. 11 are plotted $R' = n\ R$ as ordinates against F as abcissas for 33, 44, 66, 88, 110, 132, and 154 kv.

The curves in Fig. 7, 9, and 11 may be used as in the following example:

Example 3

Assume an overhead line 100 miles long, of 66-kv. and 100,000-kv-a. generating capacity. Then $F = 1$ and from the curve for 66 kv. in Fig. 11, $R' = 108$ ohms, also $R = 108$ ohms.

Assume the line to be 200 miles long, and other conditions the same as before. Then $F = 2$ and $R' = 76$ ohms, also $R = 76$ ohms.

Assume length = 100 miles, *kv-a.* = 200,000. Then $F = 1 \times 0.5 = 0.5$. $R' = 154$, and $R = 154 \times 0.5 = 77$ ohms.

Finally, assume length = 200 miles, *kv-a.* = 50,000. Then $F = 4$, and $R' = 53$. R however is now equal to $R' \times \frac{100{,}000}{50{,}000} = 53 \times 2 = 106$ ohms.

In Table V are given values of permissible resistance for various voltages, length of line, and kilovolt-ampere generating capacity for underground cables and overhead lines, based on the curves in Figs. 7, 9, and 11. These values of course represent the upper limit, and it will be found advisable in most cases to use values below these limits in order to be certain of sufficient current to give proper operation with present schemes of relaying and types of relays. Also, other considerations such as heating of the resistor, kilowatt load placed on the system by the I²R loss in the resistor, etc. must be taken into account in selecting the proper value of resistance.

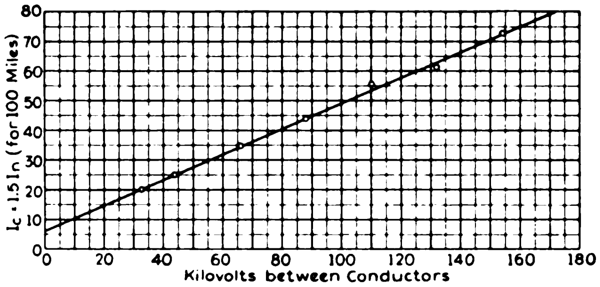


Fig. 10. Charging Current to Ground of Overhead Lines 33 to 154 kv., with One Conductor Grounded

$$I_c = (6 + 0.44\ kv.)\ \frac{\text{Length}}{100}$$

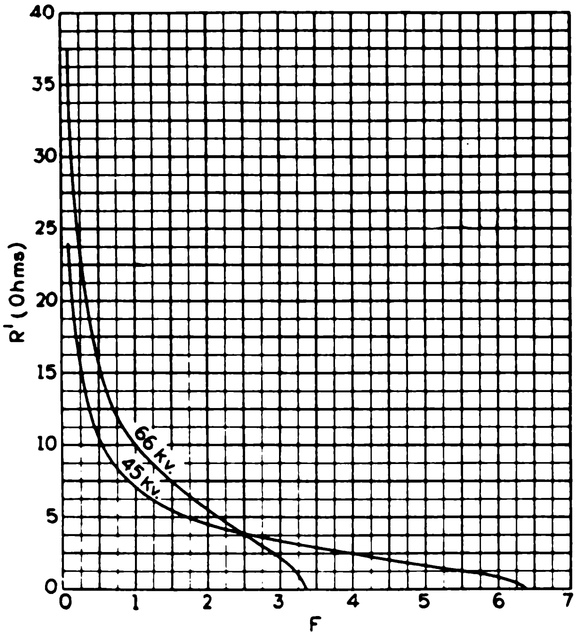


Fig. 11. Permissible Resistance for Overhead Lines 33 to 154 kv.

$$F = \frac{\text{Length}}{100} \times \frac{100{,}000}{kv\text{-}a.}$$
$$\text{Res.} = R' \times \frac{100{,}000}{kv\text{-}a.}$$

The I²R loss in the resistor has an important bearing on system stability, and it is important to avoid selecting the amount of resistance which gives maximum I^2R loss, as such a value of resistance tends to cause the greatest degree of instability. On account of this consideration it has been found desirable in some cases to use a value of resistance which is at least five times the value of the reactance in the system.

The value of resistance given by the curves and illustrated in Table V will in most cases be found to be of sufficient magnitude to satisfy this requirement. These values also appear to be reasonable, in accordance with present practice, especially on underground cable systems.

In applying the criterion under discussion to standard three-conductor underground cables, the Sectional Committee on Insulated Wires and Cables, American Standards Association, has under consideration the following rule:

> "An underground cable system is classified as having the neutral grounded when resistance in the neutral ground (or grounds) is of such value that the lagging component of short-circuit current is always equal to or greater than the total charging current of the system at the point of fault. When the neutral resistance exceeds this value the system should be classified as being ungrounded, since the conditions are such that accumulative oscillation may be caused during a failure."

REACTANCE IN THE NEUTRAL

Reactance instead of resistance in the neutral has the following advantages:

(1). Usually lower cost.

(2). Absence of I^2R loss under short circuit.

(3). The same reduction in short-circuit current may be obtained with a somewhat lower ohmic value than when resistance is used.

When reactance is employed it is usually sufficient to calculate the value of resistance by the methods previously discussed and then substitute a reactance of the same or slightly smaller ohmic value.

If it is desired to calculate a value of reactance in which the short-circuit current equals the charging current at the fault, thus giving the Petersen coil effect, Equation (1) may be modified as follows:

$$X_n = \frac{10\ kv.^2}{kv\text{-}a.} \frac{1 - x \dfrac{\sqrt{3}}{100} \dfrac{kv.}{kv\text{-}a.} I_c}{\dfrac{\sqrt{3}}{100} \dfrac{kv.}{kv\text{-}a.} I_c} \tag{10}$$

in which

X_n = neutral reactance in ohms

$kv.$ = line-to-line kilovolts

$kv\text{-}a.$ = generating kv-a. on which reactance is based

x = system reactance to point of fault expressed in per cent

I_c = charging current in ground at fault.

TABLE V

PERMISSIBLE RESISTANCE FOR VARIOUS VOLTAGES

Kv.	Miles	OHMS RESISTANCE					
		25,000 Kv-a.	50,000 Kv-a.	100,000 Kv-a.	200,000 Kv-a.	400,000 Kv-a.	500,000 Kv-a.
UNGROUNDED CABLES							
7.5	25	4.9	3.4	2.5	1.8		
12.5		9.1	6.4	4.8	3.4		
15.0		11.3	8.0	5.9	4.1		
20.0		19.2	13.7	9.7	6.2		
25.0		24.8	17.6	12.6	8.4		
33.0		33.4	23.8	17.6	11.8		
45.0		28.3	21.0	15.1	10.8		
66.0		40.4	31.3	23.1	16.7		
7.5	50	3.4	2.4	1.7	1.3	0.9	0.8
12.5		6.4	4.6	3.2	2.4	1.7	1.4
15.0		8.0	5.6	4.0	3.0	2.1	1.8
20.0		13.5	9.6	6.8	4.9	3.1	3.1
25.0		17.3	12.4	8.8	6.3	4.2	3.9
33.0		23.2	16.7	11.9	8.8	5.9	5.6
45.0		18.0	14.2	10.5	7.6	5.4	4.8
66.0		21.6	20.2	15.7	11.6	8.4	7.5
7.5	100	2.4	1.7	1.2	0.9	0.6	0.5
12.5		4.5	3.2	2.3	1.6	1.2	1.0
15.0		5.6	4.0	2.8	2.0	1.5	1.3
20.0		9.4	6.8	4.8	3.4	2.4	2.2
25.0		11.9	8.6	6.2	4.4	3.2	2.8
33.0		15.3	11.6	8.4	6.0	4.4	3.9
45.0		9.4	9.0	7.1	5.2	3.8	3.4
66.0		...	10.8	10.1	7.8	5.8	5.2
7.5	200	1.7	1.2	0.9	0.6	0.4	0.4
12.5		3.2	2.3	1.6	1.1	0.8	0.7
15.0		3.9	2.8	2.0	1.4	1.0	0.9
20.0		6.4	4.7	3.4	2.4	1.1	1.5
25.0		8.0	6.0	4.3	3.1	2.2	2.0
33.0		10.1	7.6	5.8	4.2	3.0	2.7
45.0		...	4.7	4.5	3.5	2.6	2.4
66.0		...	...	5.4	5.1	3.9	3.6
7.5	400		0.9	0.6	0.4	0.3	0.3
12.5			1.6	1.1	0.8	0.6	0.5
15.0			2.0	1.4	1.0	0.7	0.6
20.0			3.2	2.4	1.7	1.2	1.1
25.0			4.0	3.0	2.2	1.6	1.4
33.0			5.1	3.8	2.9	2.1	1.9
45.0			...	2.4	2.2	1.8	1.6
66.0			...	...	2.7	2.5	2.3
7.5	500		0.8	0.5	0.4	0.3	0.2
12.5			1.4	1.0	0.7	0.5	0.5
15.0			1.7	1.3	0.9	0.6	0.6
20.0			2.8	2.1	1.6	1.0	1.0
25.0			3.5	2.6	2.0	1.4	1.2
33.0			4.3	3.5	2.6	1.8	1.7
45.0			...	1.6	1.9	1.5	1.4
66.0			...	...	1.9	2.1	2.0
OVERHEAD LINES							
33	100		71	51	36		
44			98	70	49		
66			152	108	77		
88			206	147	105		
110			259	185	132		
132			311	226	160		
154			372	261	187		
33	200		50	36	25		
44			69	49	35		
66			106	76	54		
88			143	103	73		
110			178	130	93		
132			212	156	113		
154			240	186	131		

Example 4

As an example, assume the same conditions taken for the resistance in Example 1, Case 1:

$X = 54.4$ per cent
kv. $= 66$
kv-a. $= 100{,}000$
$I_c = 34.8$

Then

$$X_n = \frac{10 \times 66^2}{100{,}000} \frac{1 - 54.4\left(\frac{\sqrt{3}}{100} \quad \frac{66}{100{,}000} \times 34.8\right)}{\frac{\sqrt{3}}{100} \quad \frac{66}{100{,}000} \times 34.8}$$

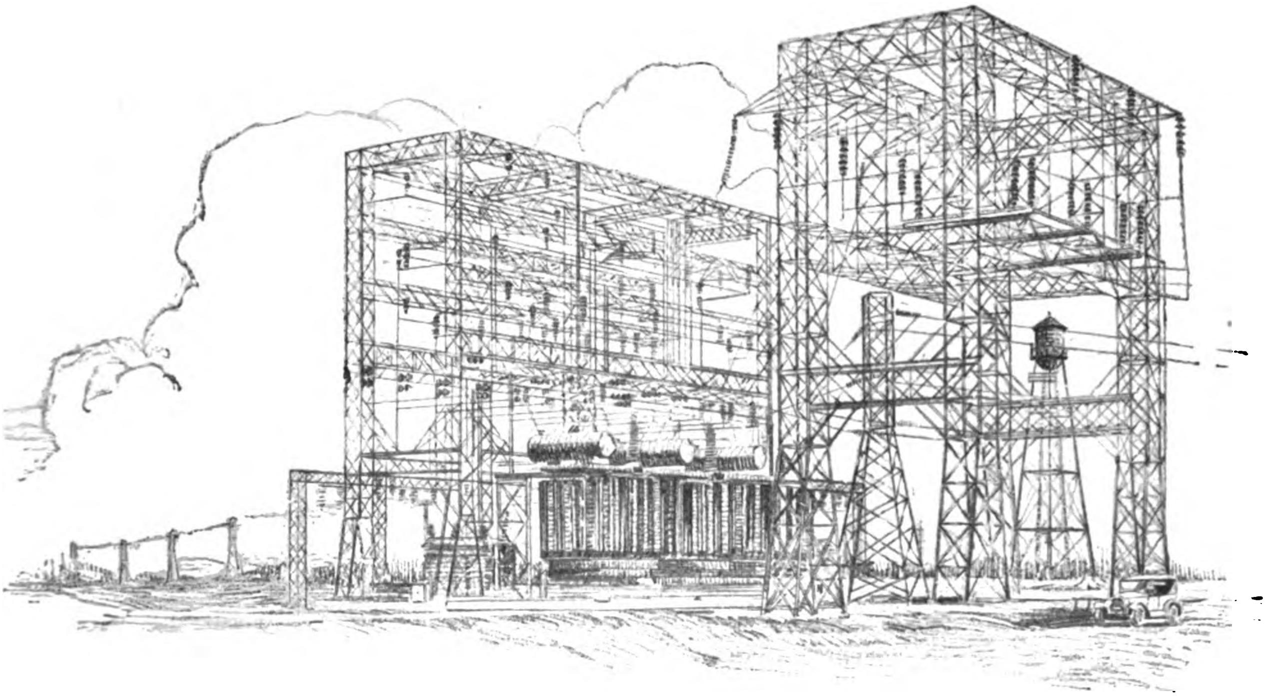
$= 1070$ ohms.

This compares with 159.5 ohms required when resistance was used in the neutral and the lagging component of the current made equal to I_c. The total short-circuit current in the resistance case, however, was equal to 236 amp. Now, with reactance in the neutral, let the short-circuit current equal 236 amp. Then from Equation (10), substituting 236 for I_c, it is found that $X_n = 138$ ohms.

For Case 2, Example 1, in which $x_3 = 0$ and $x = 24.4$, it is found that $X_n = 1084$ ohms, as compared with 108 ohms resistance. With resistance the short-circuit current was 352 amperes. If with reactance the short-circuit current be equal to 352 amp., then from Equation (10) substituting 352 for I_c, it is found that $X_n = 97.5$ ohms.

From these simple examples it is apparent that a lower value of ohms reactance in the neutral will give the same total short-circuit current than if resistance is used.

The value of 1070 to 1084 ohms found for X_n in this example are the values which would be used for the Petersen coil.



Field Tests of Super-excitation

AS APPLIED TO 30,000-KV-A. CONDENSERS AT THE PLYMOUTH MEETING SUBSTATION

By ROBERT TREAT
Central Station Engineering Department, General Electric Company

THE Conowingo transmission lines of the Philadelphia Electric Company terminate at the Plymouth Meeting Substation. In this station there are three condensers, each of 30,000-kv-a. capacity at 13 800 volts. They are excited by direct-connected exciters, rated 165 kw., 250 volts. These exciters are in turn separately excited by 40-kw. 250-volt sub-exciters. Each unit is controlled by a special voltage regulator.

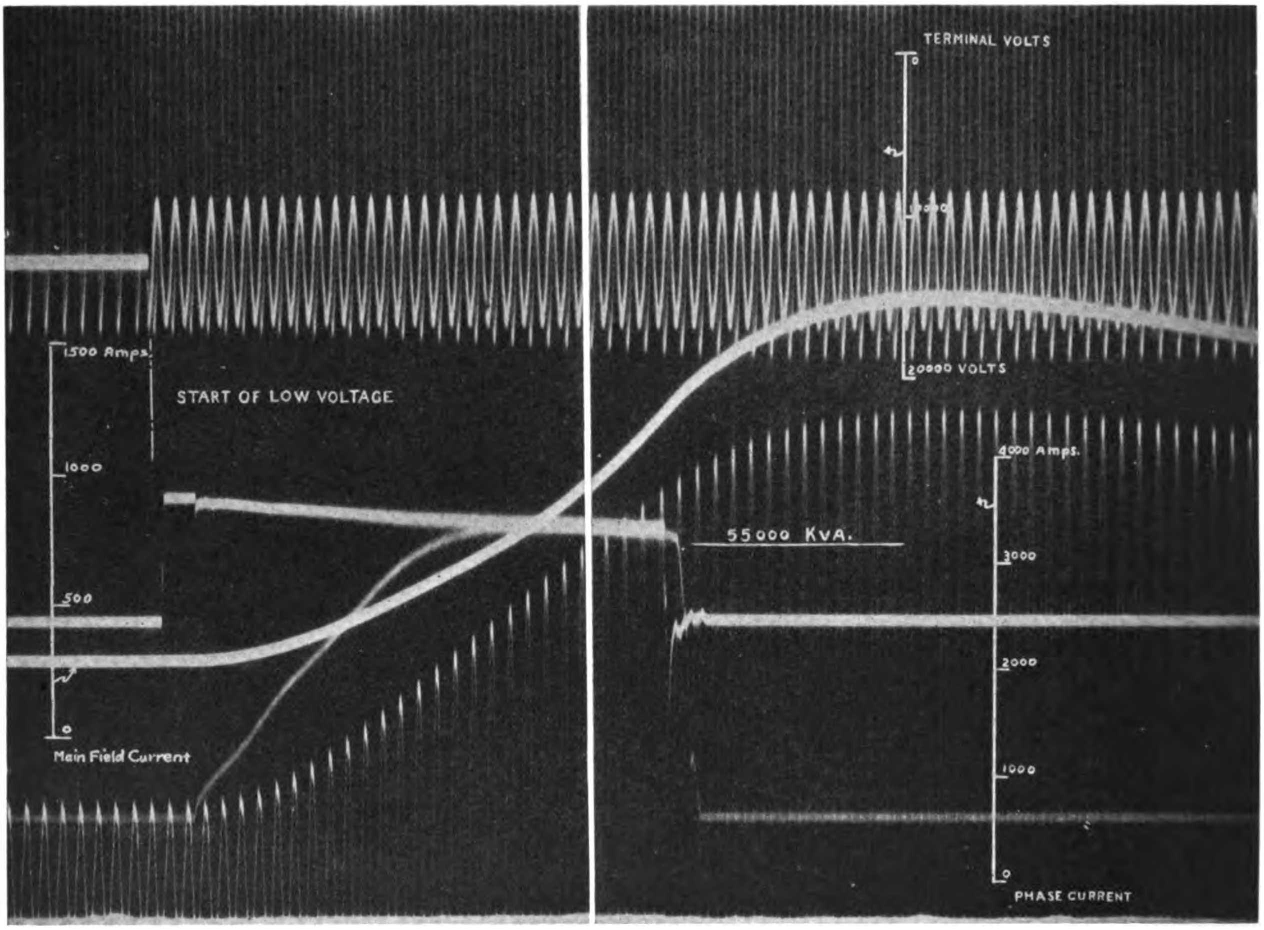


Fig. 1. Oscillogram Showing Performance of Super-excitation System as Installed. From a staged test in which the regulator was actuated by artificially depressing the voltage supplied to it

Comment in the technical press and before the A.I.E.E. has already been made regarding the super-excitation scheme used on these condensers, together with the reasons therefor.(1) These machines have been in operation for some time and a statement of their accomplishment is of interest.

The requirements to be fulfilled by the super-excitation equipment were as follows:

(1). With the condenser operating at 10,000 kv-a. leading, a system disturbance causing a reduction in line voltage of a stated amount must cause the condenser to increase its output to 55,000 kv-a. in 30.5 cycles.

(2). The regulator must control the condenser smoothly through the range 10,700 kv-a. lagging to 30,000 kv-a. leading.

The condenser itself was to be designed for 20,000 kv-a. lagging with zero excitation.

The stipulation in Condition (1) should be further clarified. Any reduction in system voltage would inherently cause an increase in the kv-a. output of the condenser, without benefit of the excitation system. Hence, to secure any measure of the effectiveness of the latter required a careful definition of the conditions on the system external to the condenser. Therefore, in checking the performance of the equipment it was agreed that the effect of low voltage on the regulator should be artificially produced, while the condenser itself should operate on a bus of substantially constant voltage. This criterion was used in calculating performance.

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(1) "Super-excitation on Synchronous Condensers for Conowingo System," by D. M. Jones, *A.I.E.E. Journal*, May, 1928, page 357.
"Super-excited Condensers," by O. A. Gustafson, *Elec. World*, Feb. 18, 1928, page 349.

It was recognized that it might be rather difficult to secure a bus the voltage of which remained substantially constant during a sudden change of 45,000 kv-a., but it was felt this condition could be closely approximated and suitable corrections made for any departures.

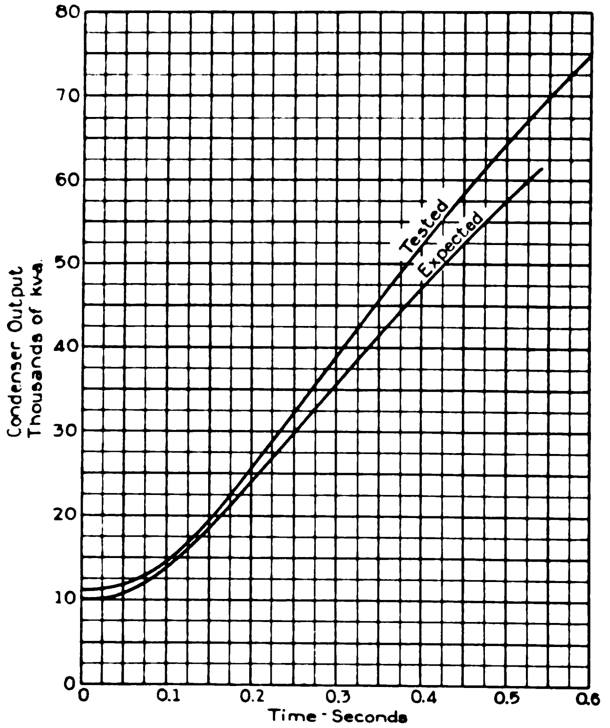

Fig. 2. Comparison of the Expected and Tested Performance of the Condenser with Respect to Increase of Output with Time

In attempting the design of an excitation system capable of increasing the leading kv-a. output of a condenser by 150 per cent of its rating in less than one-half second and of a regulator to control such a system, there was practically no past experience for guidance. The difficulty of the task may easily be appreciated, especially when it is realized that the regulator was required also to control the condenser smoothly during normal operation and with no hunting. It is not surprising, therefore, that a certain amount of adjustment and changes were required after installation.

Field tests have now been made on the equipment as finally adjusted. The performance during test is shown by the oscillogram in Fig. 1. A comparison of expected and realized performance is given by the curves in Fig. 2. In addition, it was found that the regulator smoothly controlled the condenser from its maximum value leading to 20,000 kv-a. or more lagging, a range much greater than stipulated. The tests were made by simulating a system disturbance, so far as the regulator was concerned. This was accomplished by opening a switch across a resistance in series with the regulator a-c. potential element. One vibrator of the oscillograph connected across this resistance indicated definitely the initiation of the disturbance to which the regulator and condenser were to respond.

Even on so large a system as that of the Philadelphia Electric Company, a sudden increase of 45,000 leading kv-a. caused the voltage to rise appreciably. An attempt was made to adjust the system conditions so that the condenser terminal voltage would reach normal at the exact instant that the current reached the value corresponding to 55,000 kv-a., but this was not always possible. After the tests were completed it was found the oscillograph record of condenser terminal voltage showed somewhat lower values than those read during the test on a portable voltmeter. Some doubt was then cast on the accuracy of the voltmeter.

The exact value of condenser terminal voltage at the instant when the current reached a value corresponding to 55,000 kv-a. is, therefore, not entirely certain. This uncertainty does not affect the question as to whether the performance on test equalled the expected performance, but does affect the amount of margin by which the expectation was exceeded.

This is the first installation of an excitation and regulating system whose characteristics depart so far from normal practice. When this enterprise was first undertaken, a considerable amount of skepticism was expressed as to whether it was physically possible to attain the results sought. It is most gratifying to the proponents of this scheme that their faith has been vindicated.

High-tension Cable Development

Factors Contributing to Progress—Conditions and Characteristics—Types of Cable—Joints and Terminals—Systems of Oil-filled Cables

By G. B. SHANKLIN
Central Station Engineering Department, General Electric Company

PRONOUNCED progress has been made in high-tension underground cable practice during the past three or four years, resulting not only in cable of better quality and reliability but also in greatly improved operating conditions.

Internal ionization of voids or gas spaces is now recognized as a vital and dangerous factor. Most of this recent progress has been the result of a better understanding of void formation during manufacture, installation, and operation, and of the causes and effects of ionization when conditions allow it to exist.

This progress has divided along two lines: first, improvement in ordinary types of "solid" paper-insulated cable and, secondly, the development of a new type of paper-insulated cable filled with liquid oil. The principles of the oil-filled cable have been fully described in the technical press. (1) (2) (3)

Fundamentally, the difference between the oil-filled cable and the "solid" cable is one of degree. It is simply a physical question of the viscosity of the filling compound and the resistance offered to movement of this compound in both a longitudinal and radial direction. This difference alone determines how quickly voids can be closed in the cable by oil reservoir feed and ionization troubles thereby circumvented. It has allowed the working voltage stress in oil-filled cable to become more than double the safe stress in "solid" cable, resulting in successful operation at 132,000 volts. There is every reason to believe that the present maximum voltage rating of oil-filled cable can be exceeded when the need arises.

A recent paper, "Progress in High-tension Underground Cable," (2) gives a fairly complete description of the latest knowledge regarding the theory and principles of both the "solid" and oil-filled cables. The present article will, therefore, give the briefest possible outline of this work and will then deal with some of the newer developments.

"Solid" Cable

The "solid" cable is not adaptable to exact engineering study because of the inherent physical characteristics. The extremely high resistance offered to movement of the viscous filling compound in both longitudinal and radial directions and the wide variation in this resistance with temperature, stretching of sheath during operation, quality and type of compound, etc., are factors making a study of the "solid" cable a complicated affair. However, the quality of cable offered today represents a distinct advancement. The mechanical construction is more nearly perfect. This is particularly true of the paper wrappings, these being smoothly and compactly applied, resulting in a uniform cross-sectional distribution of fiber. Consequently, little space is left in which voids of dangerous size can form.

The substitution of wood-pulp paper for manila-rope paper is an advancement. It is now possible to control density, uniformity, and purity much more closely. Filling compound has always proved a difficult problem. Only recently has it been realized that the physical characteristics are even more important than the electrical and chemical. An ideal filling compound for "solid" cable would have the following characteristics, as far as present knowledge and experience go:

(*a*). Low coefficient of expansion.
(*b*). Low viscosity at impregnating temperature, increasing to a value just sufficiently high at normal temperatures to prevent "bleeding" during the leading process and during installation in the field, and to prevent migration and building up of excessive pressure at points of low elevation. Solidifying point below the minimum temperature met with in service.
(*c*). Sticky and adhesive, forming a good, strong film.
(*d*). Low dielectric loss, high insulation resistance, and correspondingly low temperature coefficients.
(*e*). High dielectric strength.
(*f*). Chemically stable and free of all absorbed gases and other impurities.

An all-mineral compound, designated as No. 219, was developed about three years ago closely meeting these specifications. The viscosity-temperature curve is shown in Fig. 1. It will be noted that it is a non-solidifying compound, remaining a liquid even at very low temperatures.

Compound and paper of the right properties and quality are the primary requisites for a high-voltage cable. There are other factors, however, of equal importance as regards quality of finished cable and durable service. Of these, impregnation should come first. A great deal of improvement in impregnation has been accomplished in a carefully worked out process. Exact control of temperature, more thorough removal of residual gas and moisture, time and method of soaking, prevention of bleeding during the leading process, etc., have all contributed towards more perfect and uniform impregnation.

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(1)Symposium: "132-kv. Single-conductor, Lead-covered Cable," by P. Torchio, L. Emanueli, W. S. Clark, A. H. Kehoe, C. H. Shaw, J. B. Noe, and D. W. Roper, *A.I.E.E. Trans.*, Vol. 47, Jan., 1928, p. 186.

(2)"Progress in High Tension Underground Cable Research and Development," by G. B. Shanklin and G. M. J. Mackay, *A.I.E.E. Trans.*, Vol, 49. April, 1929.

(3)"A New Development in Oil Filled Cable," by G. B. Shanklin and V. A. Sheals, *Elec. World*, Jan. 12, 1929.

It can be safely stated that it is now possible to produce cable which, for all practical purposes, can be regarded as having perfect impregnation, initially, as shipped from the factory. Actually, there is a small amount of gas and void formation present, but compared with the amount formed later during installation and service and also compared with the degree of impregnation obtained a few years ago with petroleuum-filled cable, present impregnation can be considered almost perfect, provided, of course, that no incidental mistakes are made in routine manufacture. Absolute uniformity in production appears to be the only real improvement left in this direction.

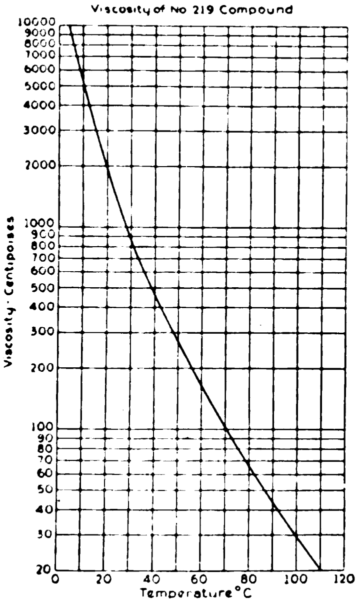


Fig. 1. Viscosity of No. 219 Compound

Now, although it is possible to manufacture "solid" cable of practically perfect initial impregnation, the problem is far from solved. Retaining this degree of impregnation throughout the operating life of the cable is the vital problem to be faced today. Inherently, the "solid" cable is unwilling to coöperate in supplying factors that contribute to the complete solution. Voids are formed by distortion of the sheath during installation and, even more so, by expansion and contraction as the cable heats and cools during service.

Supplying thin oil to the cable from expansible reservoirs at the joints helps in closing up these voids and, what is of equal importance, helps in maintaining positive pressure inside the cable. Also, metallic shielding, particularly of multi-conductor cable, assists very materially in keeping the larger voids outside of the field of stress.

One of the greatest possible helps in the successful operation of high-tension "solid" cable is in keeping the temperature range within the narrowest possible limits. American practice is not very conservative in this respect; and our standard temperature rules should be changed accordingly. The temperature range from no-load in the winter time to full-load in the summer time is too great in the average conduit system met with in this country.

The development of fixtures used with "solid" cable such as terminals, joints, reservoirs, and fittings has reached a satisfactory stage. It is now possible to obtain both terminals and joints of simple and well balanced design and construction and of even greater safety than the cable with which they are used. Thin oil filling, and the elimination of voids obtained thereby, has proved the principal solution of this problem. Special methods of stepping and the use of strong, elastic, "low-loss" varnished cambric tape for reinforcement wrappings have eliminated weakness along the "penciled" surfaces.

Oil-filled joints and terminals require reservoirs to take care of contraction and expansion. Reservoirs are also essential to the oil-filled cable. Consequently, particular attention has been paid to this development and there is now a complete line of oil reservoirs and fittings for all purposes. These consist of three different types:

I. Gravity-feed reservoirs.
II. Balanced-pressure reservoirs.
III. Straight-pressure reservoirs.

All three types follow the established principle of sealing off the oil and preventing exposure to air or other gas. The design consists of an assembly of metal disk cells, the sides of which are flexible, corrugated diaphragms. The cell stack is enclosed in a rigid metal tank. The gravity-feed reservoir has all of the cells connected in parallel by a manifold and the oil is placed inside the cells. The rigid tank is maintained at atmospheric pressure by a breather. This type of reservoir, while protecting the oil, functions exactly as would an ordinary rigid, open storage tank, requiring elevation above its surroundings for maintaining pressure.

The balanced-pressure reservoir was developed to take the place of the gravity reservoir in those cases where pressure is required but where it is impractical to obtain this by elevating the reservoir. It is similar in design to the gravity reservoir except that, instead of having a breather, the outer rigid tank is sealed off full of gas at any required pressure. It is called the "balanced-pressure" type because two or more units at different elevations can be conveniently adjusted or balanced to work together in harmony and synchronism.

In the straight-pressure type the cells are not paralleled but each cell is individually sealed off full of gas, the oil being in the outer rigid tank, which can be pumped up to any pressure desired. Owing to the fact that adjustment can be made only from the oil side, this design, while quite useful, can only be made to serve certain purposes. It is the one most generally used with "solid" cable, the other two designs being used more with oil-filled cable.

Oil-filled Cable

When compared with "solid" cable, the oil-filled cable has certain advantages as follows:

(*a*). It is possible to have uniformly perfect impregnation and maintain this throughout the life of the cable.

(*b*). It is an easy matter at any time to determine the condition of the cable by "impregnation test" and withdrawal of oil samples for test and analysis.

(*c*). Oxidation, void formation, and ionization being absent there is, as far as can be determined, an entire absence of insulation deterioration with time.

(*d*). The safe operating temperature range is greater than that for "solid" cable.

(*e*). The insulation can be worked at a voltage stress two or more times that considered safe for "solid" insulation.

(*f*). For a given voltage rating and carrying capacity the cable diameter is considerably smaller.

(*g*). Flaws and defects in the lead sheath merely result in slow leakage of oil, which can be located and repaired at any convenient time.

To balance against these advantages, there are greater complications in installation, operation, and repair of oil-filled cable, requiring careful engineering attention. As far as economy goes, it is difficult to make comparisons except in specific cases. It can be stated generally that simplifications being introduced as rapidly as possible are bringing the relative economies of the two cables closely in line.

Fig. 2 gives a brief comparison of the relative void formation in "solid" and oil-filled cable when full-load is dropped. Curve (*a*) represents the contraction inside a single conductor 66-kv. cable during cooling of the cable and duct bank. It is called the oil-demand curve, since it represents the total void volume formed that requires oil.

Curve (*b*) represents the amount of oil supplied by the reservoirs to an oil-filled cable. Curve (*c*) is a similar oil supply curve for a "solid" cable of the same cross-section impregnated with No. 219 compound (see Fig. 1). Both curves are determined on the basis of atmospheric pressure being maintained in the oil channels, representing radial feed only into the paper insulation.

The difference between Curves (*b*) and (*c*), as compared with Curve (*a*) is evident at a glance. Curve (*b*) might be called the "worst" condition for oil-filled cable because it is not difficult to maintain a pressure higher than atmospheric in the feed channels (or an oil of lower viscosity could be used), entirely eliminating the slight traces of void formation shown.

Curve (*c*), on the other hand, represents the "best" condition for solid cable. It is impracticable to maintain atmospheric pressure in the feed channels in service. Also, No. 219 oil is about the thinnest that can be used in solid cable. It will be noticed that nearly two days are required to fill up all the voids that are formed as the cable cools.

Types of Oil-filled Cable

Three types of oil-filled cable have been developed:

A. Single-conductor, hollow core.

B. Single-conductor, with channels directly under the sheath.

C. Three-conductor, with channels in the three filler spaces.

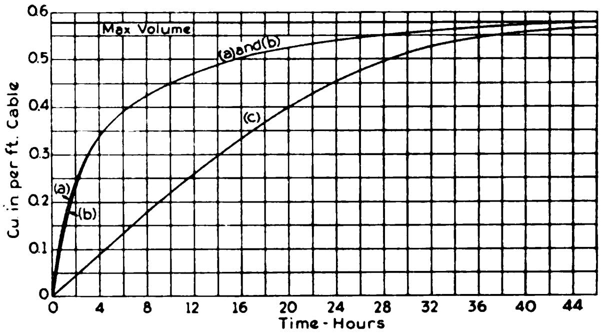


Fig. 2. Volumetric Change with Time

Curve (*a*): Oil Demand
Curve (*b*): Oil Supply—No. 1 Oil, 20 deg. C. Earth
Curve (*c*): Oil Supply—No. 219 Oil, 20 deg. C. Earth

Single-conductor cable in either type *A* or *B* is rated at all voltages up to 132 kv. and three-conductor cable (type *C*) up to 75 kv. The sheath on any of these three types may be of the ordinary, single-thickness kind, except for being made of lead alloy, or it may be of the special double reinforced design, depending upon the pressure. The single sheath will withstand a maximum working pressure of about 16 lb. per sq. in. and the double sheath about 40 lb.

Joints for Oil-filled Cable

Three types of joints for any of the foregoing types cable have been developed:

(*1*). Standard joint.

(*2*). Semi-stop joint.

(*3*). Stop joint.

The standard joint (*1*) is similar to those used with "solid" cable and allows a free interchange of oil between the adjacent cable lengths it joins together.

The semi-stop joint (*2*) has special cork seals in each end and does not allow free interchange of oil, although there is a very slight seepage of oil through the insulation around these cork seals.

The stop-joint (*3*) forms an absolute oil seal and allows no interchange of oil.

Any or all three types of joints may be used in a single line of cable, depending upon the contour met with along the line and the general plan of oil-feed system selected.

Oil-feed Systems

Different systems of oil feed have been developed; four of these are outlined below:

(*a*). Long-section plan.
(*b*). Short-section plan.
(*c*). Sectionalized balanced-pressure plan.
(*d*). Balanced-pressure plan.

These systems of oil feed may be used singly or in combination, depending upon the type of cable, the ground contour, and other determining conditions met with.

The long-section plan (*a*) was developed primarily for hollow-core single-conductor cable (*A*). Stop joints (*3*) are placed the greatest possible distance apart, as determined either by the oil pressure drop along the core or by the maximum allowable head pressure, dividing the cable line into sections of as great length as 6000 to 8000 ft. Each section is fed by a gravity reservoir (*I*) at the high end. Occasionally, this is augmented by a small straight-pressure reservoir (*III*) at the low end. A full description of the long-section plan can be found in a previously published treatise. (1)

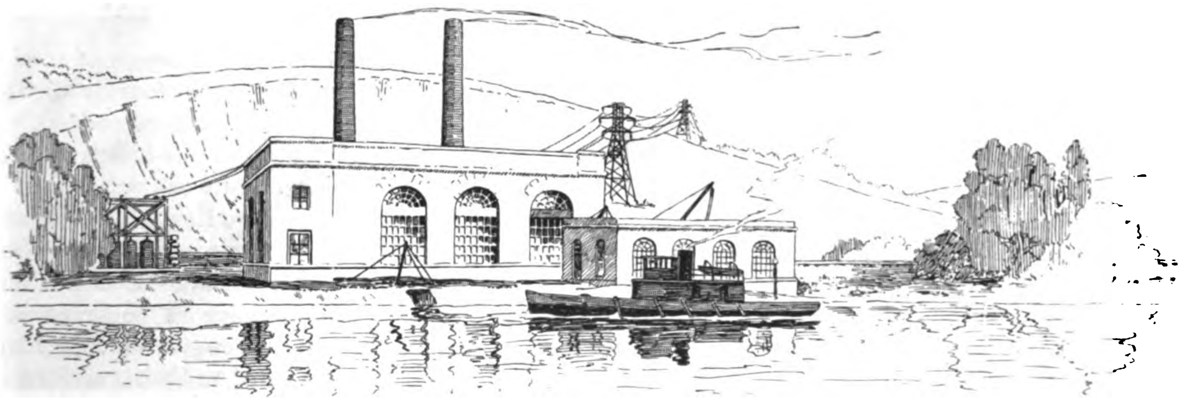
The short-section plan (*b*) was developed primarily for the purpose of having available a system of oil feed which would be independent of ground contour. Stop joints are placed every 1800 to 2000 ft., or nearer if head pressure demands it. This is essentially a low-pressure system and a reinforced sheath is not necessary. Reservoirs (*I*) and (*II*) are used in various combinations, depending upon the individual contour of each section between stop joints. The reservoir units are sufficiently small to be placed directly in the stop-joint manholes, whereas in the long-section plan special manholes or towers are necessary.

The sectionalized balanced-pressure plan was developed for three-conductor cable (*C*) and single-conductor cable (*B*). No standard joints are used, the semi-stop joint (*2*) taking its place and dividing the cable line into the shortest possible sections at every manhole. Small balanced-pressure reservoirs (*II*) are attached to each joint, the entire system of reservoirs being balanced in accordance with the contour. Stop joints are used only to break up cumulative head pressure, depending upon the contour. On fairly level ground no stop joints at all are needed. The line might continue for miles under these conditions without stop joints. This plan is fully described in a recent publication. (3)

The balanced-pressure plan (*d*) is practically the same as plan (*c*), the only difference being that standard joints (*1*) are used instead of semi-stop joints (*2*) when the conditions are such that the cable ends can be raised well above the duct level while the joints are being assembled. If conditions do not allow this, the semi-stop joint is used and after assembly the cork seals are by-passed, allowing a free passage for oil. Obviously, plan (*d*) does not give the segregation obtained with plan (*c*) but otherwise operates identically the same way.

In addition to these four plans, there are other methods of oil feed, which are not dealt with in this article, since the four that are described are representative examples.

It will be inferred from the considerations presented, that there is no universal design of oil-filled cable line that will serve all purposes. The ground contour, economy and other considerations have direct bearing upon the design that should be selected. Plans (*a*), (*b*), (*c*), (*d*), and others, may be used in various combinations in a single-cable line although, generally speaking, the best design reduces itself to a comparatively simple and obvious selection after a study of local conditions.



Tests of Metal Arc Welds

Purpose of Tests—Types of Welds—Test Specimens—Diagrams and Tabulations—Unit Stresses—Results

By ANDREW VOGEL
General Plant Construction Dept., General Electric Company

THE use of a material of any kind or quality requires knowledge of its physical properties with respect to the manner in which it is to be used. The metal arc weld is no exception to this rule and, therefore, before steel structures could be properly welded by the metal arc process, it was necessary to establish unit stresses to be used for designing the various forms of welds. In addition, it was necessary to establish confidence in the skilled application and practicable methods of inspection of welds, so that no doubt would be left in the minds of engineers regarding the reliability of welding.

Tests were made to determine unit stresses for design purposes and uniformity and reliability of the welds. The problem was not as simple as it appeared. It involved not only testing, but also the design of test specimens which would most nearly represent conditions occurring in steel structures. It also involved testing the welds without their being appreciably affected by distortion in the specimen itself. Preliminary tests were made to determine the approximate strength of welds and then the specimens were so designed that the stresses in the bars making up the specimens would not exceed the elastic limit, or preferably would not exceed 25,000 lb. per square inch.

The first specimens were made and tested during the latter part of 1927 and the results were published in the February, 1928, issue of the *Journal of the Boston Society of Civil Engineers*. These results indicated that 3000 lb. per linear inch should be the unit stress used for structural designing purposes on parallel shear welds having a minimum contact distance of $\frac{5}{16}$ in. and a maximum contact distance of $\frac{3}{8}$ in., the variation being specified to allow for the inaccuracies of workmanship. The ultimate unit stress at failure indicated a factor of safety of four or better in practically all the tension specimens and a factor of safety of five or better in practically all the compression specimens.

It appeared, however, that a series of tests involving only 24 specimens, while satisfactory for uniformity, did not completely establish reliability. Additional tests have recently been made, therefore, covering a range of specimens with welds from $\frac{1}{2}$ to 6 in. in length. These specimens included not only welds in parallel shear, where the welds were arranged directly opposite each other, but also welds in parallel shear which were diagonally opposite each other, and welds in normal shear. The results were most satisfactory. In the series of tests indicated in Fig. 1, there are a total of 173 tests. Of these tests, the $\frac{5}{16}$ and $\frac{3}{8}$-in. parallel compression opposite welds and parallel tension opposite welds from 3 to 6 in. in length are the same as were reported before the Boston Society of Civil Engineers, while the remainder are tests made during 1928.

The welds most frequently used in practice are the welds indicated as *PTO*; that is, parallel shear welds with the member in tension and the welds directly opposite each other, or with welds on the sides of the end connection of the structural member. The other welds used with almost equal frequency are the welds marked *PC;* that is, parallel shear welds with the member in compression. Welds used quite frequently are welds marked *PTD 6/6*. These are welds in parallel shear on the diagonal web members of Warren and Pratt Trusses when the web members are on a slope of 45 deg., or 6 in. vertical to 6 in. horizontal. The welds marked *PTD 6/8* are rarely used, as they are the extreme condition of the slope of diagonal web members of Pratt and Warren Trusses, when the slope of the web members is 6 in. vertical to 8 in. horizontal.

The welds marked *NT* and *NC* are used on tension and compression members where the welds must be so applied that they are placed in normal shear; that is, the stress is applied at right angles to the longitudinal axes of the weld. Up to the present time, this form of connection has been avoided because of lack of a sufficient number of tests, but the curves shown in Fig. 1 indicate that this form of welding is satisfactory. Tests have not as yet been made where normal shear and parallel shear welds are used on the same specimen.

It is common practice in the design of steel structures to use a factor of safety of four or slightly less as required by conditions or building codes. Probably a factor of safety of three and one-half is ample in all cases. In reinforced concrete work, a factor of safety of three has been considered satisfactory for some years, as a stress of 650 lb. in compression on concrete failing at 2000 lb. is normally used, and a stress of 800 lb. on the same quality of concrete is being gradually adopted. The curves given in Fig. 1 indicate that a high percentage of the $\frac{5}{16}$-in. and all of the $\frac{3}{8}$-in. welds failed at 12,000 lb. or more per linear inch, thus providing a factor of safety of at least four. The parallel-shear welds arranged on opposite sides of the member on a slope of 6 to 8 in. failed at about

11,600 lb. per linear inch, or at a value providing a factor of safety of 3.8. It is therefore apparent that welds with a minimum contact distance of $\frac{5}{16}$ to $\frac{3}{8}$ in. are satisfactory under all normal requirements for a working stress of 3000 lb. per linear inch. The tests show that the results are uniform and reliable and that arc welding can be depended on to produce a connection as satisfactory as are by any other method.

The curves shown or indicated as $\frac{1}{4}$" *PTO* and $\frac{1}{4}$" *PC* are $\frac{1}{4}$-in. welds and are shown in light dotted lines. The $\frac{1}{4}$-in. size welds are used only on angles or other members with metal $\frac{1}{4}$ in. thick. The design value used at the present time for $\frac{1}{4}$-in. welds is 2000 lb. per linear inch. The tests indicate a factor of safety of five or more in all cases. Only a very small proportion of the members used in structures have legs or metal anywhere in the section only $\frac{1}{4}$ in. thick; and usually in such cases stresses on the members are so small that even with a stress of 2000 lb. per linear inch the number of inches of welding involved is small.

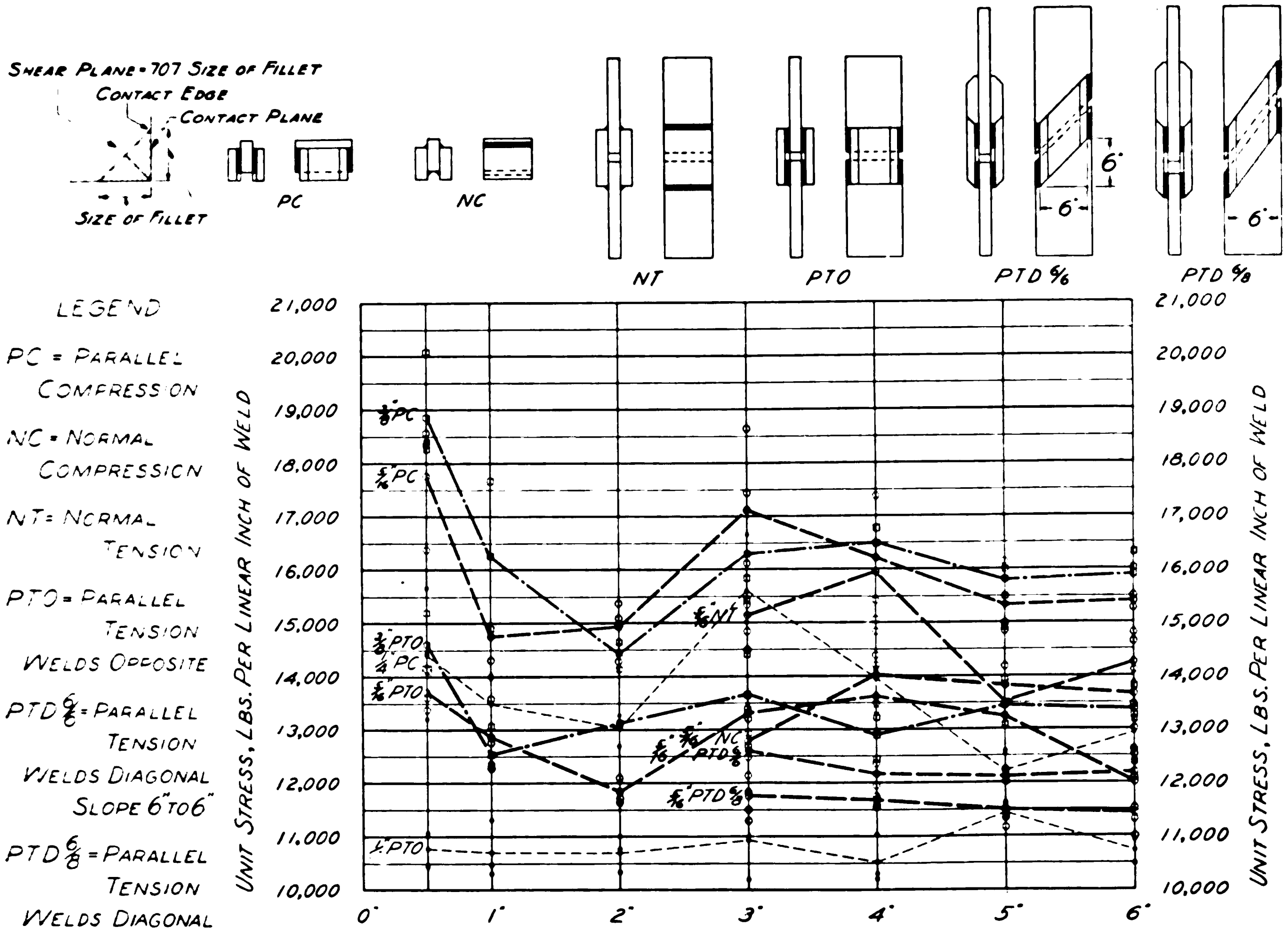
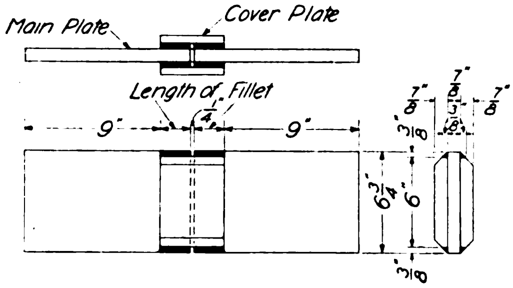


Fig. 1. Chart of Unit Stresses from Tests of Welds

The curves shown or indicated as $\frac{5}{16}$" *PTO* and $\frac{5}{16}$" *PC* have practically all of their test values above 12,000 lb. per linear inch, thus indicating a factor of safety of four when a unit stress of 3000 lb. per linear inch is used for design purposes. Most of the tests in this series were made upon $\frac{5}{16}$-in. fillets in order to determine the minimum test value of a nominal $\frac{3}{8}$-in. fillet, if a minimum contact distance of $\frac{5}{16}$ in. was accepted upon inspection, the variation from the nominal contact distance of $\frac{3}{8}$ in. being permitted to cover inaccuracies of workmanship. Experience has shown that the variation from nominal contact distance or fillet size is very slight; therefore the use of data from tests of $\frac{5}{16}$-in. fillets to determine the design value of $\frac{3}{8}$-in. welds is an error on the side of extreme conservatism.

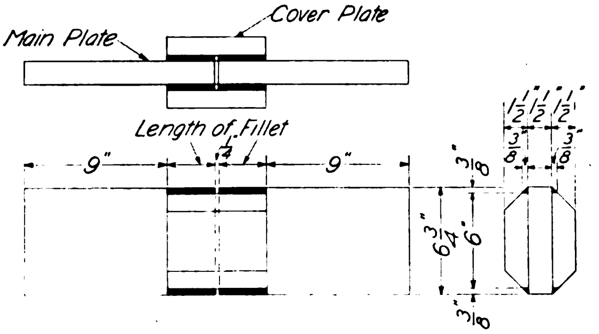
Occasionally it is necessary to use welds which cannot exceed $\frac{5}{16}$-in. contact distance because the thickness of metal to which the weld is applied is only $\frac{5}{16}$ in. In such cases, a design value of 2500 lb. per linear inch is used.

The curves indicated as $\frac{3}{8}$" *PTO* and $\frac{3}{8}$" *PC* have all of their test values above 12,500 lb. per linear inch, thus indicating a factor of safety of four or more when using a design stress of 3000 lb. per linear inch. The curves marked $\frac{5}{16}$" *NT*, $\frac{5}{16}$" *NC*, and $\frac{5}{16}$" *PTD 6/6* also have all their test values above 12,000 lb. per linear inch, indicating a factor of four when a design stress of 3000 lb. per linear inch is used.


Main Plate
Cover Plate
Length of Fillet
9"
1/4"
9"
7/8"
7/8"
7/8"
3/8"
3/16"
6 3/4"
6"
3/16"

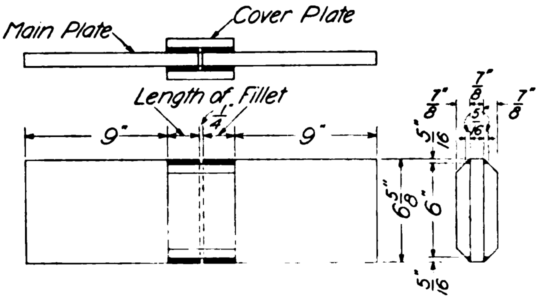
Specimen Number	Length of one Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-A	1/2"	3/8"	1 1/4"	9 1/2"			14625	13432
1	"	"	"	"	28300	14150		
2	"	"	"	"	29040	14520		
3	"	"	"	"	30420	15210		
2-A	1"	3/8"	2 1/4"	10"			12540	
1	"	"	"	"	49380	12345		
2	"	"	"	"	52310	13080		
3	"	"	"	"	48800	12200		
3-A	2"	3/8"	4 1/4"	11"			13130	
1	"	"	"	"	102920	12865		
2	"	"	"	"	108040	13505		
3	"	"	"	"	104150	13020		

Fig. 2. TENSION SPECIMENS *1-A* TO *3-A*


Main Plate
Cover Plate
Length of Fillet
9"
1/4"
9"
1/2"
1/2"
1/2"
3/8"
3/8"
3/16"
6 3/4"
6"
3/16"

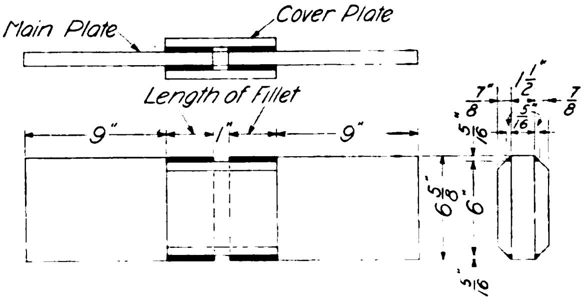
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
8-A	3"	3/8"	6 1/4"	12"			13661	13354
1	"	"	"	"	173300	14442		
2	"	"	"	"	164100	13675		
3	"	"	"	"	154400	12867		
9-A	4"	3/8"	8 1/4"	13"			12912	
1	"	"	"	"	212080	13255		
2	"	"	"	"	216100	13506		
3	"	"	"	"	191600	11975		
10-A	5"	3/8"	10 1/4"	14"			13450	
1	"	"	"	"	276580	13829		
2	"	"	"	"	268300	13415		
3	"	"	"	"	262100	13105		
11-A	6"	3/8"	12 1/4"	15"			13392	
1	"	"	"	"	317000	13208		
2	"	"	"	"	316900	13204		
3	"	"	"	"	330300	13763		

Fig. 3. TENSION SPECIMENS *8-A* TO *11-A*


Main Plate
Cover Plate
Length of Fillet
9"
1/4"
9"
7/8"
7/8"
7/8"
5/16"
5/16"
6 5/8"
6"
5/16"

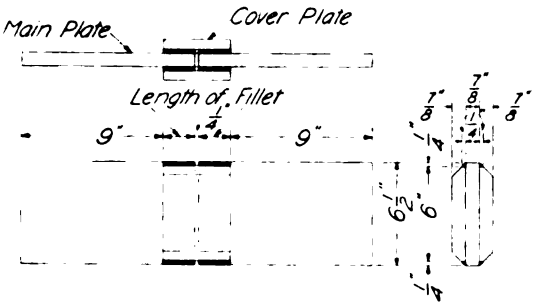
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-B	1/2"	5/16"	1 1/4"	9 1/2"			13720	12812
1	"	"	"	"	26780	13390		
2	"	"	"	"	28290	14145		
3	"	"	"	"	27260	13630		
2-B	1"	5/16"	2 1/4"	10"			12875	
1	"	"	"	"	49080	12270		
2	"	"	"	"	54380	13595		
3	"	"	"	"	51040	12760		
3-B	2"	5/16"	4 1/4"	11"			11840	
1	"	"	"	"	96850	12105		
2	"	"	"	"	93840	11730		
3	"	"	"	"	93490	11685		

Fig. 4. TENSION SPECIMENS *1-B* TO *3-B*


Main Plate
Cover Plate
Length of Fillet
9"
1"
9"
7/8"
1/2"
7/8"
5/16"
5/16"
6 5/8"
6"
5/16"

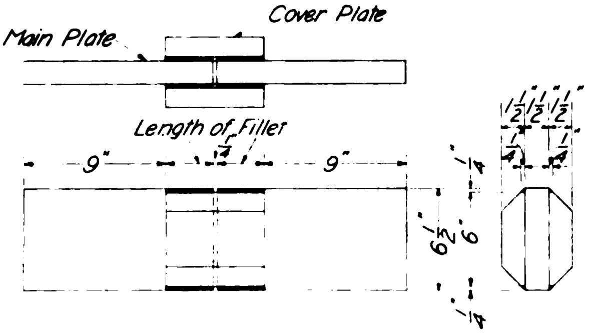
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
4-B	3"	5/16"	7"	12"			13311	13056
1	"	"	"	"	148090	12341		
2	"	"	"	"	162550	13546		
3	"	"	"	"	168550	14046		
5-B	4"	5/16"	9"	13"			13629	
1	"	"	"	"	213610	13351		
2	"	"	"	"	221260	13829		
3	"	"	"	"	219350	13709		
6-B	5"	5/16"	11"	14"			13260	
1	"	"	"	"	266920	13346		
2	"	"	"	"	260870	13044		
3	"	"	"	"	267800	13390		
7-B	6"	5/16"	13"	15"			12022	
1	"	"	"	"	276600	11525		
2	"	"	"	"	286600	11942		
3	"	"	"	"	302400	12600		

Fig. 5. TENSION SPECIMENS *4-B* TO *7-B*



Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-C	1/2	1/4	1 1/4	9 1/2				
1	"	"	"	"	22160	11080	10770	
2	"	"	"	"	20890	10450		
3	"	"	"	"	21580	10790		
2-C	1"	1/4	2 1/4	10"				
1	"	"	"	"	41250	10310	10700	10725
2	"	"	"	"	45250	11315		
3	"	"	"	"	41900	10475		
3-C	2"	1/4	4 1/4	11"				
1	"	"	"	"	82720	10340	10705	
2	"	"	"	"	86180	10770		
3	"	"	"	"	88050	11005		

Fig. 6. TENSION SPECIMENS *1-C* TO *3-C*



Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
8-C	3"	1/4	6 1/4	12"				
1	"	"	"	"	139500	11625	10917	
2	"	"	"	"	131200	10933		
3	"	"	"	"	122300	10192		
9-C	4"	1/4	8 1/4	13"				
1	"	"	"	"	176740	11046	10521	
2	"	"	"	"	163420	10214		
3	"	"	"	"	164860	10304		10899
10-C	5"	1/4	10 1/4	14"				
1	"	"	"	"	232300	11615	11441	
2	"	"	"	"	227620	11381		
3	"	"	"	"	226560	11328		
11-C	6"	1/4	12 1/4	15"				
1	"	"	"	"	257720	10738	10717	
2	"	"	"	"	262100	10921		
3	"	"	"	"	251800	10492		

Fig. 7. TENSION SPECIMENS *8-C* TO *11-C*

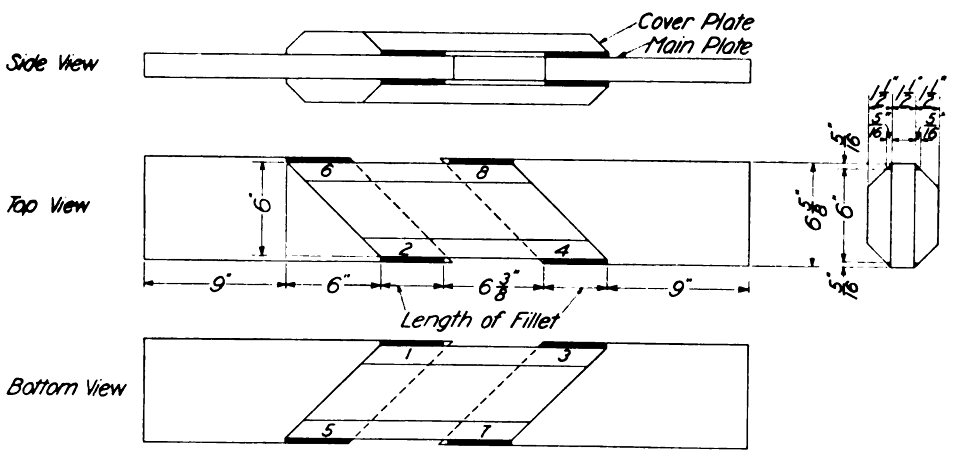
Tension specimens *1-C* to *3-C* and *8-C* to *11-C* are specimens on which the welds were located opposite each other and tested in parallel shear. The size of fillets is ¼ in.; and the fillets vary in length from ½ in. to 6 in. The tabulation gives full details and indicates that a factor of safety of five or better is provided in all cases when a design stress of 2000 lb. per linear inch is used. Welds of ¼ in. in size are used only for small members such as angles or tees where the leg is only ¼ in. thick. Inasmuch as these occur rarely and the stresses applied are usually very small, the design value of 2000 lb. per linear inch provides a weld of ample length with a high factor of safety.

◄—◄ Figs. 2 and 3. TENSION SPECIMENS *1-A* TO *3-A* AND *8-A* TO *11-A* (*See opposite page*)

Tension specimens *1-A* to *3-A* and *8-A* to *11-A* are specimens on which the welds were located opposite each other and were arranged to be tested in parallel shear by applying tension to the specimens. The size of the fillets is ⅜ in.; and the fillets vary in length from ½ in. to 6 in. The tabulation gives the total stress at which each specimen failed, stress per linear inch for each specimen, average stress for each length of weld, and the average stress for each series of tests. Particular attention is called to the uniformity of the test values, to the fact that the ⅜-in. weld is the size most frequently used in the welding of steel structures, and also that a factor of safety of four or more is obtainable when using a design stress of 3000 lb. per linear inch.

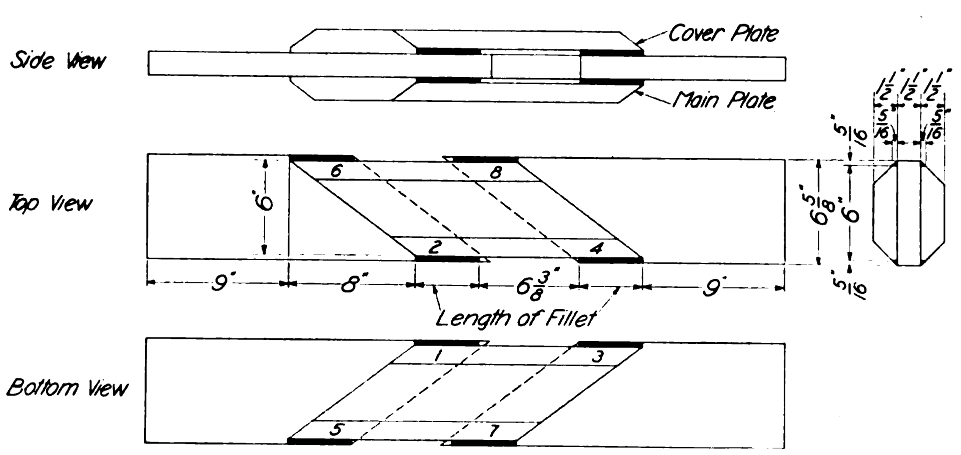
◄—◄ Figs. 4 and 5. TENSION SPECIMENS *1-B* TO *3-B* AND *4-B* TO *7-B*

Tension specimens *1-B* to *3-B* and *4-B* to *7-B* are also specimens on which the welds were located opposite each other and tested in parallel shear. The size of fillets is 5/16 in. and the fillets vary in length from ½ in. to 6 in. The tabulation is similar to that for the preceding specimens. The tests indicate a factor of safety of four or more when a unit stress of 3000 lb. per linear inch is used for design purposes on welds having a minimum contact distance of 5/16 in. and a maximum contact distance of ⅜ in., the variation being specified to cover inaccuracies of workmanship. It will be observed, therefore, that what is nominally ⅜-in. weld may have a minimum contact distance of 5/16 in. and still have a satisfactory factor of safety when using a design stress of 3000 lb. per linear inch.


Side View
Cover Plate
Main Plate
Top View
6"
6
8
2
4
9"
6"
6⅜"
9"
Length of Fillet
6⅝"
6"
5/16"
1½"
1½"
1½"
5/16"
5/16"
Bottom View
1
3
5
7

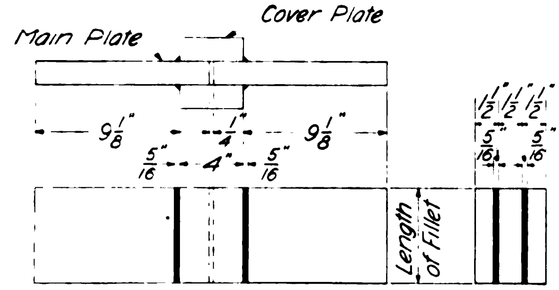
Specimen Number	Desired Length of one Fillet	Actual Length of Fillet in Inches								Total Inches of Fillet on End that failed	Fillets that Failed	Dimension "A" Inches	Dimension "B" Inches	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
		1	2	3	4	5	6	7	8								
12-B	3"											12	18⅝				12270
1	"	3	3	3	3	3	3	3	3	12	3-4-7-8	"	"	141950	11829	12590	
2	"	3	3⅛	3	3	3	3	3	3	12	3-4-7-8	"	"	152700	12725		
3	"	3	3¼	3	3	3⅛	3	3	3¼	12⅜	1-2-5-6	"	"	163550	13216		
13-B	4"											13	19⅝				
1	"	4⅛	4⅛	4	4	4¼	4	4⅛	4	16⅛	3-4-7-8	"	"	200400	12428	12175	
2	"	4	4	4	4	4	4	4	4	16	3-4-7-8	"	"	197720	12358		
3	"	4¼	4¼	4⅛	4	4⅛	4¼	4⅛	4¼	16⅞	1-2-5-6	"	"	198120	11740		
14-B	5"											14	20⅝				
1	"	5⅛	5¼	5	5	5	5¼	5⅛	5⅜	20½	3-4-7-8	"	"	247320	12064	12123	
2	"	5⅜	5⅜	5¼	5¼	5	5¼	5⅝	5⅝	21	1-2-5-6	"	"	256540	12216		
3	"	5¼	5½	5	5	5	5⅛	5⅛	5⅛	20¼	3-4-7-8	"	"	244800	12089		
15-B	6"											15	21⅝				
1	"	6½	6	6	6¼	6¼	6¼	6¼	6¼	25	1-2-5-6	"	"	302160	12086	12193	
2	"	6⅛	6	6¼	6	6¼	6	6¼	6¼	24¾	3-4-7-8	"	"	298180	12047		
3	"	6	6	6⅛	6	6	6⅛	6	6⅜	24½	3-4-7-8	"	"	304920	12445		

Fig. 8. TENSION SPECIMENS *12-B* TO *15-B*


Side View
Cover Plate
Main Plate
Top View
6"
6
8
2
4
9"
8"
6⅜"
9"
Length of Fillet
6⅝"
6"
5/16"
1½"
1½"
1½"
5/16"
5/16"
Bottom View
1
3
5
7

Specimen Number	Desired Length of one Fillet	Actual Length of Fillet in Inches								Total Inches of Fillet on End that failed	Fillets that Failed	Dimension "A" Inches	Dimension "B" Inches	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
		1	2	3	4	5	6	7	8								
16-B	3"											12	20¾				11617
1	"	3⅛	3⅛	3⅛	3¼	3	3⅛	3⅛	3¼	12¾	3-4-7-8	"	"	146760	11511	11775	
2	"	3	3¼	3	3	3	3¼	3	3	12½	1-2-5-6	"	"	156580	12526		
3	"	3⅛	3¼	3⅛	3	3⅛	3⅛	3¼	3⅛	12⅝	1-2-5-6	"	"	142510	11288		
17-B	4"											13	21¾				
1	"	4¼	4¼	4¼	4⅛	4⅛	4	4¼	4¼	16⅝	1-2-5-6	"	"	198600	11945	11709	
2	"	4½	4½	4⅛	4	4⅛	4	4¼	4¼	16⅝	3-4-7-8	"	"	193080	11613		
3	"	4¼	4⅛	4⅛	4¼	4⅛	4⅛	4¼	4¼	16⅝	1-2-5-6	"	"	192340	11569		
18-B	5"											14	22¾				
1	"	5	5	5	5	5¼	5	5⅛	5	20¼	1-2-5-6	"	"	229720	11344	11522	
2	"	5¼	5⅜	5⅛	5	5⅛	5⅛	5¼	5¼	20⅞	1-2-5-6	"	"	252060	12074		
3	"	5⅛	5¼	5⅛	5	5⅛	5⅛	5⅛	5⅜	20⅝	1-2-5-6	"	"	230920	11147		
19-B	6"											15	23¾				
1	"	6¼	6⅜	6	6	6¼	6	6	6¼	24¼	3-4-7-8	"	"	266740	11000	11460	
2	"	6	6	6	6	6	6	6	6	24	3-4-7-8	"	"	271480	11312		
3	"	6⅛	6¼	6	6	6¼	6	6¼	6¼	24⅝	1-2-5-6	"	"	297200	12069		

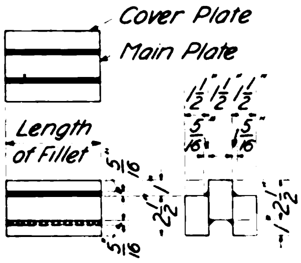
Fig. 9. TENSION SPECIMENS *16-B* TO *19-B*



Specimen Number	Length of one Fillet	Size of Fillet	Length of Cover Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
4-E	3"	5/16	4"				14715
1	"	"	"	89000	14833	15138	
2	"	"	"	86850	14475		
3	"	"	"	96630	16105		
5-E	4"	5/16	4"				
1	"	"	"	120500	15063	15951	
2	"	"	"	123350	15416		
3	"	"	"	139000	17375		
6-E	5"	5/16	4"				
1	"	"	"	149610	14961	13514	
2	"	"	"	122100	12210		
3	"	"	"	133700	13370		
7-E	6"	5/16	4"				
1	"	"	"	176650	14721	14257	
2	"	"	"	160880	13407		
3	"	"	"	175700	14642		

Fig. 10. TENSION SPECIMENS *4-E* TO *7-E*

Tension specimens 4-*E* to *7-E* are specimens on which the welds were located normal to the longitudinal axis of the specimens and were arranged to be tested in normal shear, that is, when tension was applied to the specimens the welds were tested in shear in a direction normal to the longitudinal axis of the weld. The tabulation gives the stresses at failure. The test results are quite uniform with every weld, showing a factor of safety of four or more when using a design stress of 3000 lb. per linear inch. This type of weld is used at the ends of members when the members are either in compression or tension. While this form of weld is not used to any appreciable extent, still there are occasions when it is the most desirable form of weld to use. This form of weld, however, should not be confused with the butt weld performing a similar function, as these specimens are only intended to imitate welds used on the ends of compression and tension members of trusses.



Specimen Number	Length of one Fillet	Size of Fillet	Width of Cover Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
4-E	3"	5/16	2½				13582
1	"	"	"	145610	12134	12799	
2	"	"	"	155000	12917		
3	"	"	"	160150	13346		
5-E	4"	5/16	2½				
1	"	"	"	215900	13494	14031	
2	"	"	"	230180	14386		
3	"	"	"	227400	14813		
6-E	5"	5/16	2½				
1	"	"	"	277850	13893	13819	
2	"	"	"	267600	13380		
3	"	"	"	283650	14183		
7-E	6"	5/16	2½				
1	"	"	"	318000	13250	13678	
2	"	"	"	354800	14783		
3	"	"	"	312000	13000		

Fig. 11. COMPRESSION SPECIMENS *4-E* TO *7-E*

Compression specimens *4-E* to *7-E* are specimens on which the welds were arranged to be tested in normal shear by applying compression to the specimens. The size of fillets is $\frac{5}{16}$ in.; and the fillets vary in length from 3 in to 6 in. If a design stress of 3000 lb. per linear inch is used, a factor of safety of four or more is apparent in all cases. As mentioned before, in commenting upon tension specimens *4-E* to *7-E*, this type of weld is not extensively used, but data are necessary in case occasion arises where this form of weld is the most suitable for the location. The test specimens were distorted in the testing machine, thus producing combined shear and tension in the welds; but the recorded test value is only that given on the balance beam of the testing machine, as it was impossible to estimate the effect of the combined stresses

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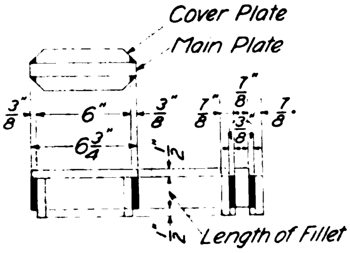
◄— Fig. 8. TENSION SPECIMENS *12-B* TO *15-B*

Tension specimens *12-B* to *15-B* are specimens on which the welds were located diagonally opposite each other on a slope of 6 in. to 6 in. and on which the welds were arranged to be tested in parallel shear by applying tension to the specimens. This arrangement of welds was used in order to imitate arrangement of welds used on Warren and Pratt Trusses. The size of fillets is $\frac{5}{16}$ in.; and they vary in length from 3 in. to 6 in. The tabulation is similar to that for preceding specimens. Particular attention is called to the uniformity of the test values and also that a factor of safety of four or more is obtained when a unit-stress of 3000 lb. per linear inch is used for design purposes on welds having a minimum contact distance of $\frac{5}{16}$ in. and a maximum contact distance of ⅜ in. The tests also indicate that it is not necessary to reduce the unit stress used for design purposes when the welds are located diagonally opposite each other rather than directly opposite each other.

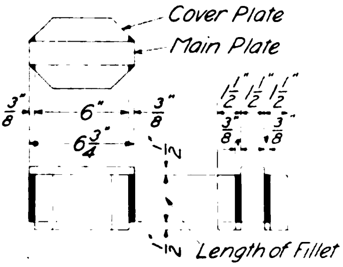
◄— Fig. 9. TENSION SPECIMENS *16-B* TO *19-B*

Tension specimens *16-B* to *19-B* are specimens on which the welds were located diagonally opposite each other on a slope of 6 in. to 8 in. and on which the welds were arranged to be tested in parallel shear. This is the maximum condition to be expected in trusses. The size of fillets is $\frac{5}{16}$ in.; and they vary in length from 3 in. to 6 in. The tabulation is similar to that for preceding specimens. The test values are very uniform and indicate that a factor of safety of four or more is obtained when a design stress of 2500 lb. per linear inch is used. The test values also show a factor of safety of 3.8, when a design stress of 3000 lb. per linear inch is used on welds having a minimum contact distance of $\frac{5}{16}$ in. and a maximum contact distance of ⅜ in. This factor of safety is entirely satisfactory as most welds used on steel structures are ⅜-in. welds.


Cover Plate
Main Plate
3/8"
6"
3/8"
7/8"
7/8"
3/8"
7/8"
6 3/4"
1/2"
1/2"
Length of Fillet

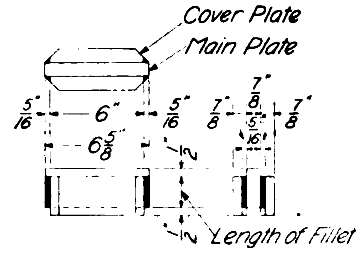
Specimen Number	Length of one Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-A	1/2"	3/8"	1"	1"			18880	16528
1	"	"	"	"	36470	18235		
2	"	"	"	"	36580	18290		
3	"	"	"	"	40220	20110		
2-A	1"	3/8"	1 1/2"	1 1/2"			16260	
1	"	"	"	"	59230	14805		
2	"	"	"	"	70680	17670		
3	"	"	"	"	65230	16305		
3-A	2"	3/8"	2 1/2"	2 1/2"			14445	
1	"	"	"	"	117000	14625		
2	"	"	"	"	116000	14500		
3	"	"	"	"	113660	14208		

Fig. 12. COMPRESSION SPECIMENS *1-A* TO *3-A*


Cover Plate
Main Plate
3/8"
6"
3/8"
6 3/4"
1/2"
1/2"
1/2"
3/8"
3/8"
1/2"
1/2"
Length of Fillet

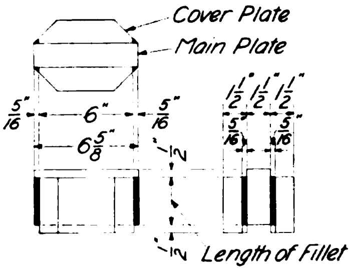
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
8-A	3"	3/8"	3 1/2"	3 1/2"			16317	16126
1	"	"	"	"	185000	15417		
2	"	"	"	"	190100	15842		
3	"	"	"	"	212300	17692		
9-A	4"	3/8"	4 1/2"	4 1/2"			16487	
1	"	"	"	"	268700	16793		
2	"	"	"	"	259600	16225		
3	"	"	"	"	263100	16444		
10-A	5"	3/8"	5 1/2"	5 1/2"			15797	
1	"	"	"	"	318300	15915		
2	"	"	"	"	319500	15975		
3	"	"	"	"	310200	15510		
11-A	6"	3/8"	6 1/2"	6 1/2"			15904	
1	"	"	"	"	391700	16321		
2	"	"	"	"	370400	15433		
3	"	"	"	"	383000	15958		

Fig. 13. COMPRESSION SPECIMENS *8-A* TO *11-A*


Cover Plate
Main Plate
5/16"
6"
5/16"
7/8"
7/8"
5/16"
7/8"
6 5/8"
1/2"
1/2"
Length of Fillet

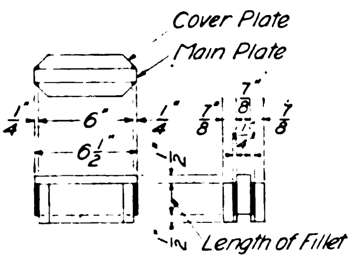
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-B	1/2"	5/16"	1"	1"			17770	15818
1	"	"	"	"	32760	16380		
2	"	"	"	"	36730	18365		
3	"	"	"	"	37140	18570		
2-B	1"	5/16"	1 1/2"	1 1/2"			14760	
1	"	"	"	"	One end not welded			
2	"	"	"	"	60790	15200		
3	"	"	"	"	57260	14315		
3-B	2"	5/16"	2 1/2"	2 1/2"			14925	
1	"	"	"	"	123820	15475		
2	"	"	"	"	114310	14290		
3	"	"	"	"	120080	15010		

Fig. 14. COMPRESSION SPECIMENS *1-B* TO *3-B*


Cover Plate
Main Plate
5/16"
6"
5/16"
6 5/8"
1/2"
1/2"
1/2"
5/16"
5/16"
1/2"
1/2"
Length of Fillet

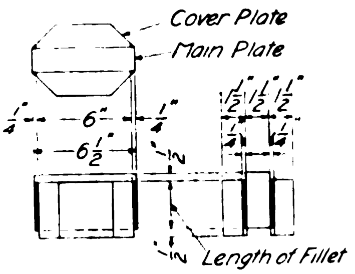
Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
4-B	3"	5/16"	3 1/2"	3 1/2"			17131	16027
1	"	"	"	"	184000	15333		
2	"	"	"	"	223500	18625		
3	"	"	"	"	209200	17433		
5-B	4"	5/16"	4 1/2"	4 1/2"			16223	
1	"	"	"	"	237500	14844		
2	"	"	"	"	278000	17375		
3	"	"	"	"	263200	16450		
6-B	5"	5/16"	5 1/2"	5 1/2"			15338	
1	"	"	"	"	297500	14875		
2	"	"	"	"	322700	16135		
3	"	"	"	"	300100	15005		
7-B	6"	5/16"	6 1/2"	6 1/2"			15414	
1	"	"	"	"	366800	15283		
2	"	"	"	"	370800	15450		
3	"	"	"	"	372200	15508		

Fig. 15. COMPRESSION SPECIMENS *4-B* TO *7-B*



Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
1-C	½"	¼"	1"	1"			14440	13657
1	"	"	"	"	31330	15665		
2	"	"	"	"	26430	13215		
3	"	"	"	"	28890	14445		
2-C	1"	¼"	1½"	1½"			13505	
1	"	"	"	"	49600	12400		
2	"	"	"	"	55910	13975		
3	"	"	"	"	56560	14140		
3-C	2"	¼"	2½"	2½"			13025	
1	"	"	"	"	101620	12700		
2	"	"	"	"	104730	13090		
3	"	"	"	"	106260	13280		

Fig. 16. COMPRESSION SPECIMENS *1-C* TO *3-C*



Specimen Number	Length of the Fillet	Size of Fillet	Length of Cover Plates	Length of Main Plates	Total Stress	Stress per Linear Inch of Weld	Average Stress	General Average Stress
8-C	3"	¼"	3½"	3½"			15611	13681
1	"	"	"	"	180000	15000		
2	"	"	"	"	200000	16667		
3	"	"	"	"	182000	15167		
9-C	4"	¼"	4½"	4½"			13948	
1	"	"	"	"	217600	13600		
2	"	"	"	"	225700	14106		
3	"	"	"	"	226200	14138		
10-C	5"	¼"	5½"	5½"			12222	
1	"	"	"	"	251700	12585		
2	"	"	"	"	231000	11550		
3	"	"	"	"	250600	12530		
11-C	6"	¼"	6½"	6½"			12943	
1	"	"	"	"	302700	12613		
2	"	"	"	"	332900	13871		
3	"	"	"	"	296300	12346		

Fig. 17. COMPRESSION SPECIMENS *8-C* TO *11-C*

Compression specimens *1-C* to *3-C* and *8-C* to *11-C* are specimens on which the welds were arranged to be tested in parallel shear by applying compression to the specimens. The size of fillets is ¼ in.; and the fillets vary in length from ½ in. to 6 in. If a design value of 2000 lb. per linear inch is used on ¼-in. welds, then these specimens indicate a factor of safety of six or better in all cases.

◄◄ **Figs. 12 and 13. COMPRESSION SPECIMENS *1-A* TO *3-A* AND *8-A* TO *11-A***

Compression specimens ***1-A*** to ***3-A*** and ***8-A*** to ***11-A*** are specimens on which the welds were arranged to be tested in parallel shear by applying compression to the specimens. The size of fillets is ⅜ in.; and the fillets vary in length from ½ in. to 6 in. The tabulation gives the stresses at failure, and particular attention is called to the uniformity of the test values and to the fact that when using a design stress of 3000 lb. per linear inch, a factor of safety of five or more is obtained in all cases. The higher values indicated by compression specimens is possibly due to the fact that the specimens are very short and that little or no noticeable distortion occurs in the specimen while testing. On the tension specimens, there is a noticeable bending in cover plates which undoubtedly causes additional stress in the welds normal to the stress produced by the testing machine;and while the combined stresses produce failure, the recorded test value is only that given on the balance beam of the testing machine. If the combined stresses in tension specimens could be determined accurately, undoubtedly the combined stresses would indicate about the same results as shown in the compression specimens. But, of course, if the unit stress which must be used on structures is the lowest shown by test methods which imitate construction methods, then we are compelled to use tension specimens as a guide rather than compression specimens. On the other hand, it is necessary to know the strength of welds used on compression members as these members are in general use on all steel construction.

◄◄ **Figs. 14 and 15. COMPRESSION SPECIMENS *1-B* TO *3-B* AND *4-B* TO *7-B***

Compression specimens ***1-B*** to ***3-B*** and ***4-B*** to ***7-B*** are specimens on which the welds were arranged to be tested in parallel shear by applying compression to the specimens. The size of fillets is $\frac{5}{16}$ in.; and the fillets vary in length from ½ in. to 6 in. The tabulation gives the data in the usual form and indicates a factor of safety of five or more in practically all cases when using a design stress of 3000 lb. per linear inch.

The curve (Fig. 1) marked $\frac{5}{16}$" *PTD 6/8* has its test values between 11,000 and 12,000 lb. per linear inch. If a design value of 2500 lb. per linear inch is used, a factor of safety of four or more is obtained. If the test values are proportionately increased for $\frac{3}{8}$-in. welds, it will be found that a factor of safety of more than four is obtainable when a design stress of 3000 lb. per linear inch is used for $\frac{3}{8}$-in. welds.

The group of curves given at the beginning of this article justify very considerable study as they combine a large number of tests which establish unit stresses of 2000 lb. per linear inch for $\frac{1}{4}$-in. welds; 2500 lb. per linear inch for $\frac{5}{16}$-in. welds; and 3000 lb. per linear inch for $\frac{3}{8}$-in. welds. In addition to establishing unit stresses, the tests also show that welding is both uniform in strength and entirely reliable.

The data of Fig. 1 illustrate the results of 173 tests involving 1040 welds with a total of 3614 linear inches of welding. Of these tests, 42 are on $\frac{1}{4}$-in. welds, 89 on $\frac{5}{16}$-in. welds, and 42 on $\frac{3}{8}$-in. welds. The data on the $\frac{1}{4}$-in. welds are given, although to date no welds less than $\frac{5}{16}$-in. contact distance have been used on any General Electric structures. Practically all welds failed on the shear plane; and when any welds failed on the contact plane, bits of parent metal were always torn out, indicating thorough fusion.

The uniformity of the results of the large number of tests, made on specimens prepared by many welders producing only such welds as are regularly used on production or construction work, proves that welding is no longer in the developmental stage but can now be assigned to a definite place in the structural steel industry. All welding was performed in a routine manner, so that the tests would be a true index of the strength to be expected on ordinary building construction work. No special requirements were established nor were any special precautions taken to improve the quality of the work. The only rule followed was that a weld once started was continued to the end of the weld. The electrodes used were $\frac{3}{16}$-in. electrodes regularly used on production or construction work and the current did not exceed 200 amp. A General Electric portable welding set provided the current; and the arc voltage was about 20 volts. Conditions were the same on all welds, observation being that greater speed was obtainable on the $\frac{1}{4}$-in. welds than on the larger fillets. With the exact unit stress for design purposes definitely established, it is now possible to design structures of all kinds and sizes without further concern regarding strength, uniformity, and reliability.

The results of the tests indicated by the curves in Fig. 1 are given in tabular form below each of the succeeding illustrations in order that the original test data may be conveniently available for more detailed study. The drawings and tables are even more impressive than the curves in proving uniformity and reliability.

The tests described in this article were made at the Rensselaer Polytechnic Institute under the supervision of Professor T. R. Lawson, of the Department of Civil Engineering; and the tabulations were prepared from his original test reports. More tests undoubtedly will be made, but the tests reported herein are ample for the design of steel structures and to convince even the most skeptical that the strength, uniformity, and reliability of arc welding has been established; and that another valuable process has been added to the resources of engineering.

View of a Welded Factory Building in Course of Erection

Operating Economies of the All-electric Ship

By **FRANK V. SMITH**

Federal and Marine Department, General Electric Company

THE fuel consumption of a steam vessel, no matter whether the vessel is propelled by turbine-electric drive, turbine-gear drive, or reciprocating engines, is the resultant of many correlated factors working together. The general and all-inclusive term "pounds of fuel per shaft horsepower-hour for all purposes" therefore has little significance in a comparative sense unless the interplay of the factors producing it are correctly evaluated.

In the present article it is endeavored to look down the long pathway of causation and trace broadly the interplay of the many items which compose the whole and to clarify, if possible, the subject of "comparative economic efficiencies of ships."

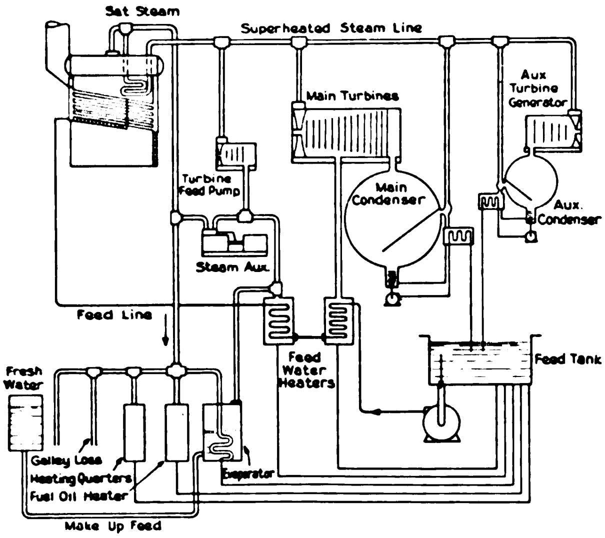


Fig. 1. Diagram of Steam Distribution System

There are two major power problems to be dealt with in any ship installation. The first of these is that of power generation for the main propulsion of the ship; the second, that of power generation for the auxiliary power needs. The relation that these two power needs hold one to the other is specific for a given vessel only. Vessels in which these two power needs are not proportionate are obviously not comparable unless some fair means is found for reducing the overall results to a common denominator.

Vessels which have similar characteristics, but which differ in respect to the type of main propelling equipment installed, are comparable only when the type of auxiliary equipment, the initial and final steam conditions, the boiler efficiency and the heat value of the fuel are identically the same on the ships being compared. There are well-known thermodynamic differences which emanate from differences in pressure, superheat, vacuum, methods of heating the feed, water, boiler design and the heat value of the fuel, which although affecting the overall efficiency of a ship, cannot be accredited to any particular virtue in the specific type of main propelling machinery installed.

For the purpose of segregating the mechanical efficiencies of the main propelling equipments from the thermodynamic differences referred to in the preceding paragraph, a complete analysis of a ship's engineering plant is given herewith. In the body of the analysis, results of which are shown on Tables I, II, and III, the work is divided into four columns in order to evaluate correctly the gains in economies resulting from the adoption of higher initial pressures and superheats. Layouts Nos. 1 and 2 are identical to the S. S. *California* and *Virginia* respectively; Layouts Nos. 3 and 4 are studies of the same installations operating at advanced steam conditions.

The main propelling equipment is of the turbine-electric type, and consists of two main turbine-generators, a control equipment for maneuvering the ship, and two propelling motors of the synchronous-induction type, each of which is directly connected to a propeller shaft. The auxiliary power plant consists of four 500-kw., direct-current, turbine-driven generators which operate condensing. Two auxiliary condensers, each of which is equipped with its own circulating and condensate pumps, and air ejector, take care of the exhaust steam of the four sets. A simple diagrammatic presentation of the steam cycle is shown in Fig. 1.

Under operating conditions at sea two of these sets are required. One set supplies current for excitation and motor ventilation and the other current to the ship's power bus. A number of the electrically-driven auxiliaries are provided with double-throw switches so they can be operated from either the excitation or power bus. This permits the loads on the generators to be divided approximately equally.

The feed water heating system consists of two feed water heaters of the closed type, connected in series. The low-pressure heater uses steam extracted from the main turbines at a pressure of approximately 2 lb. gauge and elevates the temperature of the feed water to about 195 deg. F. The second heater utilizes steam auxiliary exhaust of which there is a sufficient amount to elevate the temperature from 195 deg. F. to 230 deg. F.—the final temperature of the feed water.

The water rates given under Layouts Nos. 1 and 2, Table I, are the results of actual test records with a small amount added to cover any slight throttling losses that might ensue in practice through the throttling of hand valves. Three hand valves are provided on the main turbines which gives seven different combinations of settings without throttling the steam pressure in the main turbine bowl.

The auxiliary power needs and steam consumption are shown in Table II and the totals are carried over-to Table I. The fuel consumption figures are based on the pounds of steam generated, divided by the actual pounds of steam evaporated per pound of fuel at the conditions given in the table.

Table III gives data on the feed water heating system, the pounds of steam entering the main condensers per hour, and the calculations for the evaporation per pound of fuel oil. Under the subheading, "Explanation of Values Used in the Calculated Analysis," the method of evaluating the auxiliary power needs on a fair basis is described.

Space of course does not permit the inclusion of all of the interesting individual calculations leading up to an analysis of this kind, but it is hoped that, from what is given, the reader may get an idea of what constitutes a thermodynamic analysis. The calculation of a specific layout operating under variable power conditions is altogether too lengthy to include in an article of this kind as it consists of another entire series of calculations.

Explanation of Values Used in Calculated Analysis

In the calculations it has been attempted to keep all values (except those which are directly affected by a change in the initial steam conditions) on a constant basis, in order that the true economic differences caused by this factor may be correctly evaluated.

The power required by the main circulating pumps is calculated on the basis of 80 lb. of circulating water per lb. of steam condensed, pumped against a total head of 26 ft. with an 80 per cent efficient pump, and a motor of 92 per cent efficiency. The feed pump is assumed to be of the turbine-driven centrifugal type, pumping against a head 25 lb. in excess of boiler pressure and having an efficiency of 50 per cent. The steam consumption of the turbine which drives the feed pumps is based on a single-stage turbine turning at 3000 r.p.m. and exhausting against a back pressure of 10 lb. gauge pressure.

The power for the forced draft blowers assumes that 260 cu. ft. of air per lb. of fuel burned is used,

TABLE I

ANALYSIS OF STEAM AND FUEL CONSUMPTION, TURBINE ELECTRICALLY PROPELLED PASSENGER LINER—TWIN SCREW—17,000 SHAFT HORSEPOWER

BASIC CALCULATIONS SHOWING ECONOMIC DIFFERENCES DUE TO INITIAL STEAM CONDITIONS

Layout	No. 1	No. 2	No. 3	No. 4
Operating Conditions:				
Shaft horsepower	17,000	17,000	17,000	17,000
Propeller r.p.m.	120	120	120	120
Speed in knots	18.0	18.0	18.0	18.0
Tons displacement	32,000	32,0000	32,000	32000
Steam Conditions:				
Pressure at turbine throttle	250 lb. g.	275 lb. g.	350 lb. g.	550 lb. g.
Superheat at turbine throttle	100 deg. F.	200 deg. F.	264 deg. F. (700 deg.)	245 deg. F. (725 deg.)
Vacuum in. Hg (referred to 30-in. barometer)	28.5	28.5	28.5	28.5
Theoretical water rate	6.525	6.02	5.57	5.27
Water Rates: (Actual)				
Main turbines: without extraction or admission, lb. per propeller s.h.p-hr	9.05	8.14	7.48	7.15
Auxiliary turbine 500-kw. d-c. generators, lb. per kw-hr	16.0	14.6	13.5	12.8
Steam Consumption:	Lb. per hr.	Lb. per hr.	Lb. per hr.	Lb. per hr.
Main turbines, without extraction or admission	153,850	138,380	127,160	121,550
Admit at main turbine throttle in lieu of extraction	7,800	6,500	5,350	4,075
Total to main turbines	161,650	144,880	132,510	125,625
Auxiliary d-c. turbine generators	12,370	11,050	10,100	9,550
Steam auxiliaries	7,700	7,015	6,950	8,665
Steam for other purposes	1,880	1,835	1,790	1,750
Total steam consumption	183,600	164,780	151,350	145,590
Lb. steam per s.h.p.-hr. for all purposes	10.8	9.70	8.9	8.55
Fuel Consumption: Based on				
Fuel oil of 18,500 B.t.u. per lb.; feed water temp. of 230 deg. F.; and a boiler efficiency of 82.0 per cent actual evaporation per lb. of fuel oil—above basis	14.18	13.46	13.02	12.98
Lb. of fuel per hour	12,950	12,250	11,625	11,200
Lb. fuel oil per s.h.p-hr., all purposes	0.762	0.720	0.683	.066
Tons fuel oil per day	139	131.0	124.5	120
Knots per ton of fuel oil	3.1	3.29	3.47	3.60
B.t.u. per s.h.p.	14,100	13,300	12,625	12,200
Overall thermal efficiency	18.05 per cent	19.15 per cent	20.1 per cent	20. 8 per cent

TABLE II

AUXILIARY POWER REQUIREMENTS

Basic Calculations for Study of Economic Differences Due to Changing Designed Initial Steam Conditions

Layout	No. 1	No. 2	No. 3	No. 4
Electric Auxiliary Load:	Kw.	Kw.	Kw.	Kw.
Excitation and motor ventilation	185.0	185.0	185.0	185.0
Main circulating pumps	154.0	139.0	128.0	124.0
Forced draft blowers	25.0	23.5	22.7	22.0
Other auxiliary equipment including auxiliary-condenser, circulating and condensate pumps, main condensate, sanitary pumps, fresh water pumps, lighting, electric cooking and baking, ship's ventilation, refrigeration, steering gear, oil cooler, circulating pump, elevators, etc.: Average estimated load	355.0	355.0	355.0	355.0
Total average load	719.0	702.5	690.7	866.0
W/R.-aux. generators (2 units operating, divided load)	17.2	15.7	14.6	13.9
Lb. steam per hour	12,370	11,050	10,100	9,550
Steam Auxiliaries:	Lb. per hr.	Lb per hr.	Lb. per hr.	Lb. per hr.
Feed pump; turbine-driven centrifugal	4,600	4,050	4,100	5,900
Air ejectors main and aux. condensers	1,750	1,615	1,500	1,415
Lubricating oil pump (reciprocating)	750	750	750	750
Fuel oil service and transfer pumps	600	600	600	600
Total lb. per hr.	7,700	7,015	6,950	8,665
Steam for Other Purposes:				
Steam for heating fuel oil	880	835	790	750
Steam for galley and hot water service	1,000	1,000	1,000	1,000
Steam for heating vessel	Seasonal			
Total lb. per hr.	1,880	1,835	1,790	1,750

TABLE III

FEED WATER HEATING SYSTEM AND GENERAL OPERATING INFORMATION

Layout	No. 1	No. 2	No. 3	No. 4
Feed Water Heating System:				
Extract from main turbines for low pressure feed water heater lb. per hr.	18,000	15,500	13,500	11,500
Admit at main turbine throttle in lieu of extracted steam	7,800	6,500	5,350	4,070
Steam auxiliary exhaust available at 10 lb. g. for h-p. feed water heater exclusive of air ejectors	5,950	5,400	5,450	7,250
Calculated temperatures:				
Feed tank (allowing 5 deg. F. for radiation)	109.5	109.5	109.0	110.
Temp. rise l-p. feed water heater	89.5	89.0	86.5	72.5
Temp. rise h-p. feed water heater	31.0	31.5	34.5	47.5
Final temp. feed water	230 deg. F.	230 deg. F.	230 deg. F.	230 deg. F.
Main Condensers:				
Pounds steam per hour to 2 main condensers,	143,650	129,380	119,010	114,125
b.h.p. of main circulating pumps based on pumping 80 lb. of water per pound of steam condensed against a 26-ft. head; pump efficiency assumed 80 per cent	188.0	170.0	156.0	150.
Kw. with 91 per cent efficient motor	154.0	139.0	128.0	124.0
Evaporation Per Lb. Fuel Oil:				
Total heat of 1 lb. of steam at boilers, B.t.u.	1,267	1,325	1,364	1,367
Heat in feed water (230 − 32)	198	198	198	198
Heat to be supplied by fuel	1,069	1,127	1,166	1,169
Heat value of fuel—assumed	18,500	18,500	18,500	18,500
Average operating boiler efficiency (assumed)	0.82	0.82	0.82	0.82
Actual evaporation per lb. fuel oil	14.18	13.46	13.02	12.98

that the pressure at the fan outlet is 1½ in. of water and that the fan efficiency is 45 per cent.

It is assumed that the steam consumption of the air ejectors is reduced proportionately to the amount of available energy in the steam at the higher pressures and superheats.

The steam for heating the fuel oil is based on elevating the temperature from 70 deg. to 210 deg. F. and an oil having a "specific heat" value of 0.45.

In the feed water temperature calculations it was assumed that the temperature of the condensate in the hotwell of the condensers was four degrees less than the vacuum temperature corresponding to 28.5 inches of vacuum. A loss of 5 B.t.u. per lb. of condensate was also assumed as being fair to compensate for any radiation losses that might exist in the feed water heating system.

The pounds of steam extracted from the main turbines for feed water heating, its heat value, and the pounds of steam necessary to admit at the main throttle in lieu thereof, to keep the power output constant, were carefully calculated by means of condition curves laid out on a total heat entropy diagram.

Fig. 2 shows the water rates on the 500-kw. auxiliary generator sets. In the calculations it has been assumed that two of these generators divide the load. The steam consumption has been figured on the water rates applying at the partial loads under consideration.

In the entire calculations a distinct effort has been made to keep the calculations within the bounds of normally attainable values in actual practice. Layout No. 1 is similar to the installation on the S.S. *California* and, from data previously published, it may be noted that the values check almost exactly. Layout No. 2 is similar to the installation on the S.S. *Virginia* and fuel rates better than the calculated values have already been established. Layouts Nos. 3 and 4 are studies of the economies in the higher pressure and temperature regions.

Rankine Cycle and Transmission Efficiency

In making comparisons between the actual overall efficiencies of turbine-electric, and turbine-gear drive, the evaluations must be made under identical steam, vacuum and load conditions, otherwise thermodynamic differences which affect the mechanical efficiency creep in, which in turn offset the true relative values.

Superheated steam increases the mechanical efficiency approximately one per cent for each 50 deg. because of the reduction in the rotational losses; an increase in pressure and vacuum have a tendency to reduce slightly the mechanical efficiency, and high-powered turbines are inherently more efficient than low-powered ones.

Providing the equipments being analyzed are of the same power and operate under the same steam conditions, the "overall efficiency on the Rankine cycle" is the only criterion of relative values. It is comprehensive in its scope and includes both the turbine and transmission efficiency when the value is calculated for the power delivered at the propeller shaft.

The transmission efficiency on the other hand does not include the turbine efficiency, as it only designates the efficiency between the turbine shaft and propeller shaft. A very inefficient turbine might be connected to a highly efficient gear, and show a transmission efficiency of 98½ per cent, but have a very low overall Rankine cycle efficiency.

The answer to the question of relative efficiencies of turbine-gear drive and turbine-electric drive therefore resolves itself to a matter of comparing the overall Rankine cycle efficiencies, under identical steam, vacuum and load conditions. There is no other method by which comparisons can rightfully be made. To use fuel consumption as a criterion of the specific relative efficiency of any given type of propelling equipment is utter nonsense when the hundred and one variable factors intervening between the main power plant and fuel pile are considered.

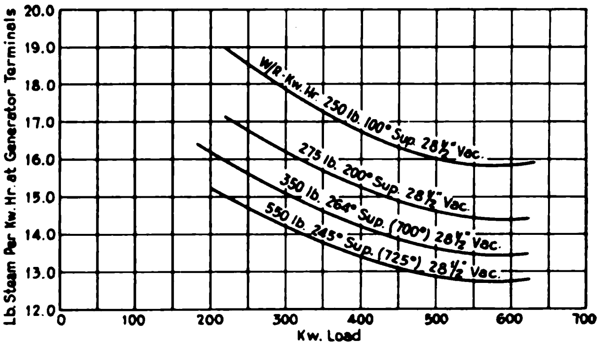


Fig. 2. Typical Water Rate Curves of 500-kw. Auxiliary-generator Sets

The contentions of the advocates of turbine-electric drive are simply this: that the main turbine being built in one casing, operating in one direction, having no reversing element, having the minimum number of shaft packings, and having no cross over connection losses, has less inherent losses than a turbine built in several casings as a compromise measure to accommodate the gears.

Another factor that favors a high efficiency in a turbine-electric plant is that the speed of the turbine can be independently selected. In turbine-gear installations (of the single reduction type) the turbine speeds are relatively low. Small power and low speed are two factors that ruin the efficiency of any turbine as all designers know.

A turbine-electric drive is more efficient on the driving end and less efficient on the transmission end; and turbine gear drive is less efficient on the driving end and more efficient on the transmission end. The product of the two values is the only answer to this much discussed subject.

Now how may the overall Rankine cycle be checked? Two factors are required: the theoretical water rate, which is the pounds of steam theoretically required to produce one horsepower hour; and the actual water rate stated in terms of pounds of steam per propeller shaft horsepower-hour. The theoretical water rate divided by the actual water rate gives the Rankine cycle efficiency. In order to simplify the work, Fig. 3 has been prepared which gives the theoretical water rates for steam at various pressures and superheats expanded to 28.5 inches of vacuum. The curves are based on the well-known formula $\frac{2545}{H_1-H_2}$ in which H_1 = the total heat of the steam at initial pressure, and H_2 = the total heat of the steam at the end of expansion.

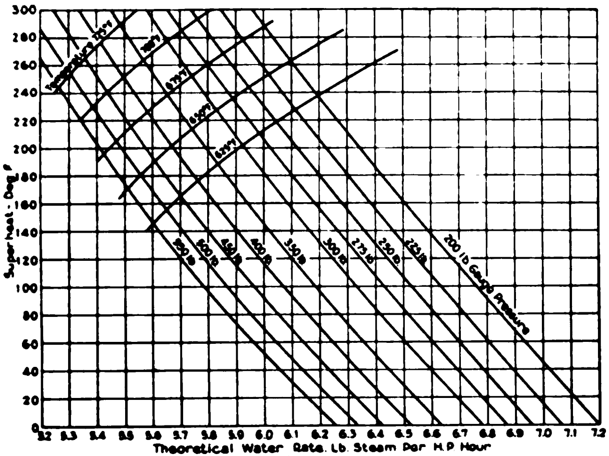


Fig. 3. Theoretical Water Rate Curves—Pounds of Steam Per Horsepower-hour

In an electric drive installation the actual water rates are generally given in terms of pounds of steam per propeller shaft horsepower-hour including the generator and motor losses, but exclusive of current used for excitation and motor ventilation. The reason for not including this latter item is because, in ship installations, it is supplied from an outside source and its relative value will, therefore, vary according to the water rate of the auxiliary generator which supplies it.

A concrete example will show the method of calculation. In Table I, Layout No. 1, it will be noted that the water rate at the propeller shaft is given at 9.05 pounds per propeller shaft horsepower-hour; in Table II it will be noted that the power for excitation and motor ventilation amounts to 185 kilowatts and that the water rate of the auxiliary generator is 17.2 pounds. The pounds of steam required for excitation and motor ventilation therefore equal 185 times 17.2 or 3182 pounds which divided by 17,000 shaft horsepower, gives a value of 0.187 pounds per shaft horsepower-hour. The water rate in this particular instance, including the motor, generator, excitation, and motor ventilation losses, therefore, equals 9.05 plus 0.187 or 9.237 pounds per hour. Referring to Fig. 3, we find the theoretical water rate for the given steam conditions to be 6.625 pounds. The overall efficiency on the Rankine cycle is therefore 6.625 divided by 9.237 or 71.7 per cent. Calculating by the same method, the overall efficiencies for Layout Nos. 2, 3 and 4 are 72.5, 73 and 72.2 per cent respectively.

The transmission efficiency, which is of little comparative significance in an economic sense, is given herewith to settle the long drawn-out arguments concerning it. It represents the losses between turbine output and propeller shaft output. The combined motor and generator efficiency in Layouts Nos. 1, 2, 3 and 4 is 95.7 per cent; the water rate at the turbine shaft is, therefore, 9.05 times 0.957 or 8.65 pounds per horsepower-hour. The water rate at the propeller shaft including excitation and motor ventilation is 9.237 pounds as before. The transmission efficiency which equals $\frac{\text{b.h.p.}}{\text{s.h.p.}}$ therefore, equals 8.65 divided by 9.237 or 93.7 per cent.

Likewise if we want to know the turbine efficiency on the Rankine cycle efficiency we can divide 6.625 by 8.65 which gives 76.5 per cent.

Economic Benefits of Auxiliary Electrification

The relative overall efficiencies obtainable with auxiliary electrification and with steam auxiliaries is subject to correct evaluation only by means of a thorough thermodynamic analysis of specific layouts, and not by generalization. The efficiency of the steam auxiliaries used, the percentage of the total steam used by them, and the uses that may be found for the disposal of the exhaust, all have a direct bearing on the subject. As a general rule, if all of the auxiliaries on a ship are driven by steam and are non-condensing, there exists a large excess of auxiliary exhaust steam above that which can be utilized in the feed water heaters.

If this excess were by-passed to the main condensers it would start a series of pyramidal losses that would be quite disastrous to the economies. In the first place it would do one of two things—either reduce the vacuum and lower the power output of the main power plant, or cause an increased duty to be placed on the circulating pump. In the latter case the auxiliary steam consumption is again increased and this in turn requires a slight speeding up of the feed pumps, the forced draft blowers, the condensate pump and the fuel oil pumps.

On the other hand, if the excess auxiliary exhaust steam were by-passed to the main turbines, it would perform work and relieve slightly the amount of steam required at the main turbine throttle. Theoretically at least the latter method has a good deal in its favor; practically it may not work out so well. Long auxiliary exhaust lines accumulate condensate, the auxiliaries may carry oil over into the condensers and, at reduced powers of the main turbines, the vacuum may extend well up into the turbine. The results are blade erosion, poor heat transfer in the condenser because of fouled tubes, and the realization of but a small amount of power because of the large pressure drop between the auxiliary exhaust line and the stage of the turbine at which steam is admitted. The use of a mixed pressure type of turbine also increases the amount of steam entering the condensers.

Now in steam vessels in which steam auxiliaries are used we find all degrees of economies from good to bad. The only method of determining relative efficiencies is to determine first the true operating characteristics of the steam plants we wish to compare and then to perform that difficult task of computing complete heat balances in each case.

Auxiliary electrification is one of the finest methods of improving the economy of operation of a ship. The gains, however, are never 100 per cent of the differences shown by the relative auxiliary steam consumption of the two methods. If all of the auxiliaries are electrified the heating of the feed water must be accomplished by other methods than the use of auxiliary exhaust. When steam is extracted from the main turbines for feed water heating, the steam so extracted—not having had an opportunity to complete its cycle—represents a power loss. This power loss must be made up by admitting an additional amount of steam at the throttle. The amount of steam admitted at the throttle in lieu of that extracted depends upon the initial and final steam conditions of the turbine, the turbine efficiency, and the pressure at which the steam is extracted.

When the extraction method of heating the feed water is resorted to, the theoretical gains realized through raising the feed water temperature must be modified by the fractional coefficient represented by $1.0-\frac{W}{W_1}$ in which W equals the weight of the steam admitted at the throttle in lieu of extraction, and W_1 equals the weight of the steam extracted.

Claims of an increase in the overall operating economies of as high as 16 per cent attributed to auxiliary electrification and steam extraction have been noted by the writer for cases in which the auxiliary steam amounted to approximately 25 per cent of the total. This leaves a margin of 9 per cent for the auxiliaries and nothing for feed water heating. To elevate the temperature of condensate from vacuum temperature (28.5 inches = 91 deg. F.) to 230 deg. F. requires approximately 12½ per cent of the total steam generated at 10 lb. gauge pressure. If this 12½ per cent is extracted from the main turbines at 10 lb. gauge pressure, approximately 50 per cent of this amount of steam must be admitted at the throttle. Nine per cent for auxiliaries (probably very low) and 6¼ per cent admitted in lieu of extraction gives a total of 15¼ per cent with which to compare the original 25 per cent. The saving, therefore, becomes 9¾ per cent instead of the original 16 per cent referred to in the beginning. To this 9¾ per cent should be added the differences in the auxiliary power requirements of the condenser auxiliaries, and the differences in the leakages which affect the makeup of feed water. This latter item of course is difficult of appraisal by slide rule methods.

Auxiliary Power from the Main Power Plant

A number of references have been made in the technical press regarding the great economic benefits to be derived from taking the auxiliary power from the main propulsion generators instead of from separately driven auxiliary-generator sets. There is opportunity for quite a little confusion regarding how much these economies amount to unless the savings are tied down to a specific installation in each case. It is obvious that, if the water rate of an auxiliary generator set is as good as that of the main unit, there is no saving between the two methods. The particular item that affects the water rate of a turbine-driven auxiliary generator is its size or rating, and this in turn depends upon

TABLE IV

ECONOMIC DIFFERENCES—TURBINE-DRIVEN AUXILIARY GENERATORS—GENERATOR SETS

Layout	No. 1	No. 2	No. 3	No. 4
Electric auxiliary power load (see Table II)—kw.	719	702.5	690.7	686
Less aux. condenser auxiliaries	25	25.0	25.0	25
New auxiliary d c. load	694	677.5	665.7	661
W/R at main unit for m-g. set	14.1	12.7	11.65	11.1
Steam consumption, lb. per hr	9,800	8,600	7,750	7,350
Previous steam consumption	12,370	11,050	10,100	9,550
Saving, lb. per hr	2,570	2,450	2,350	2,200
Air ejector for aux. cond's	600	555	515	485
Total saving, lb. steam per hr	3,170	3,005	2,865	2,685
Total steam consumption basic layout (see Table I) lb. per hr	183,600	164,780	151,350	145,590
Saving through use of m g. set	3,170	3,005	2,865	2,685
New steam consumption	180,430	161,775	148,485	142,905
Lb. fuel per hr. new	12.750	12,000	11,400	11,000
Lb. fuel per s.h.p-hr.	0.75	0.705	0.67	0.647
Tons of fuel per day	136.5	128.5	122	117.8
Saving in tons per day	2.5	2.5	2.5	2.2
Per cent saving	1.8	1.9	2.0	1.8

the extent of the auxiliary power requirements on a given ship.

It is difficult to dispense with direct current for auxiliary purposes on a ship and, therefore, when it is desired to derive auxiliary power from the main propulsion generators which produce alternating current, some means of conversion must be resorted to. The usual method of accomplishing this is by means of a motor-generator set. A motor-generator set operated from the main propulsion generators necessarily has the same speed characteristics as that of the main unit. During maneuvering or at reduced speeds of the vessel some other means for driving the direct-current generator must be provided. The usual method of accomplishing this is to connect a small turbine in tandem with the motor-generator set, thus making what is generally termed a three-unit set. When the ship is operating steadily at near full speed, the alternating-current motor drives the direct-current generator and the small turbine idles, and when the ship is maneuvering or operating at low speeds the turbine drives the load and the alternating-current motor idles.

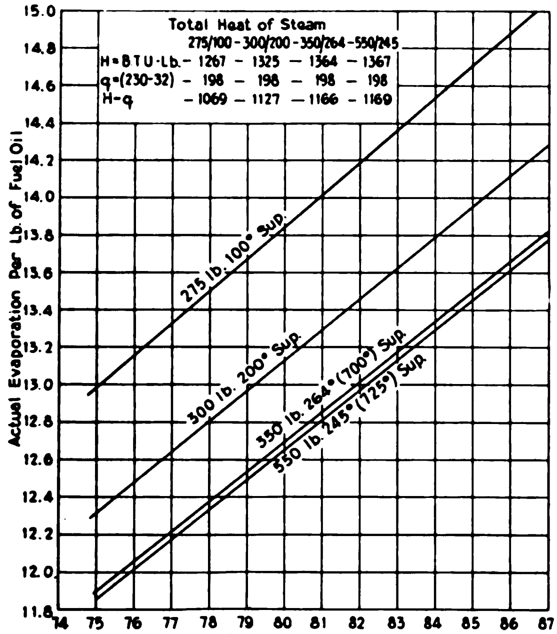


Fig. 4. Curves Showing Actual Evaporation Per Pound of Fuel Oil

The conversion efficiency of the motor-generator set must also be taken into account. A concrete example will show how the relative economies would be affected in Layout No. 1 if this system were adopted. Referring to Table I, the water rate of the main turbine at the propeller shaft is 9.05 pounds per horsepower-hour; the propelling motor efficiency is 98.2 per cent which gives a water rate at the generator terminals of 8.88 pounds per horsepower or 11.9 pounds per kilowatt-hour at the main generator terminals. Assuming the combined motor-generator set efficiency to be 84.5 per cent the water rate per kilowatt at the generator terminals of the motor-generator set would be 14.1 pounds. Referring to Table II it will be noted that the water rate of the turbine driven auxiliary generator is 17.2 pounds. The auxiliary direct-current load would also be reduced in amount because of the elimination of an auxiliary condenser circulating pump, and auxiliary condensate pump; one air ejector would also be eliminated.

A complete revision of the calculations and a comparison of the relative economies is given in Table IV for Layouts form Nos. 1 to 4 inclusive.

Boiler Efficiency Heat Value of Fuel and Actual Evaporation Per Pound of Fuel

One of the most important factors from the standpoint of economical ship operation is that of boiler efficiency. It is a factor which is influenced both by the boiler design and the operating intelligence of the crew. From the latter standpoint, good atomization of the fuel oil, which requires clean burners, oil heated to the proper temperature and proper air regulation, are the main requisites.

In Fig. 4 are plotted curves of the actual evaporation per pound of fuel for the steam conditions given in Layouts Nos. 1, 2, 3, and 4, based on fuel oil having a heat value of 18,500 B.t.u. per pound, and feed water of a temperature of 230 deg. F. For fuel oil having a heat value of 19,000 B.t.u. per pound the actual evaporation per pound of fuel should be increased by 2.63 per cent.

In ship operating practice the boiler efficiency is one of the most difficult items to obtain; it may vary between wide limits on different ships, and until some method is devised for its correct appraisal, it precludes the possibility of using fuel consumption alone as a means of gauging the relative efficiencies of steam plants.

In the basic calculations a normal value of 82 per cent was used throughout, a figure which seems to be amply justified by the actual results obtained on several modern vessels. The extreme value of 87 per cent on the chart can undoubtedly be obtained when air preheaters or economizers are installed, and by very careful and constant adjustment of the air supply by the operating personnel. In Fig. 5 are shown curves of fuel consumption under varying boiler efficiency values, for Layouts Nos. 1, 2, 3 and 4.

Increasing the Economies

From a theoretical point of view it is quite interesting to apply the latest innovations in economic power practice and to presume the most favorable operating conditions. In this respect we might assume (1) that either air preheaters or economizers are installed which permits an 87 per cent boiler efficiency being maintained in place of the 82 per cent used in the basic calculations; (2) that the heat value of the fuel is 19,000 B.t.u. per pound instead of 18,500; (3) that a vacuum of 29.0 inches instead of 28.5 inches is maintained; (4) that multiple-stage feed water heaters sufficient to elevate the temperature of the feed water to 300 deg. F. instead of 230 deg. F. are included; and (5) that the auxiliary electric power is taken from the main power plant by means of a motor-generator set instead of from separate turbine generator sets.

The per cent corrections to the basic calculations would be approximately as follows:

	Per Cent Gain
Boiler efficiency, 82 to 87 per cent	5.75
Fuel oil, 18,500 to 19,000 B.t.u.—lb	2.63
Vacuum 28.5 to 29.0 inches	3.00
Feed temperature 230 deg. to 300 deg. by extraction	2.15
Auxiliary power from motor-generator set	1.80
Total gain, per cent	15.33

A comparison of the fuel rates as calculated in the basic standards and as revised would be as shown in Table V.

Some of the modern large central stations are now producing a kilowatt-hour at the switchboard terminals for about 13,500 B.t.u.; this amounts to an overall thermal efficiency of 25.3 per cent from the coal pile to the available power delivered on the outgoing power buses. In considering the possibility of attaining as high an overall thermal efficiency on a ship as has been obtained in central station practice, there are several items which favor the ship, and several which favor the power house. The auxiliaries on a ship are more extensive than in a central station, but the main power operates on a much higher average load factor. Generally speaking these opposing factors may nearly cancel each other, but again of course, we must take instances that are comparable and not installations chosen at random.

One might ask if the new fuel rates calculated under Layout No. 4 represent the best that can be expected in the future steam plant on a vessel, and if all means of increasing the economies have been exhausted. This may be answered in the negative. We still might apply re-superheating as an additional economic measure, and also install scoop condensers on a high speed vessel, thus doing away with the main circulating pumps at sea. We might also elevate the initial pressure and superheat providing the metallurgical arts safely permit it. A fuel rate of 0.50 pounds of oil per propeller shaft horsepower for all purposes, therefore, appears to be within the realms of possibility for large high-speed vessels which operate on trade routes in which cold sea water permits a vacuum of 29.0 inches to be maintained.

TABLE V

A COMPARISON OF FUEL RATES

Layout	No. 1	No. 2	No. 3	No. 4
Basic fuel rate, lb. per s.h.p-hr	0.762	0.72	0.683	0.66
New fuel rate	0.645	0.61	0.578	0.558
New overall thermal efficiency	20.7 per cent	21.9 per cent	23.2 per cent	24.0 per cent

Conclusions

A close study of the factors which affect the fuel consumption of a vessel will it is believed bring out the fallacy of using the fuel rates of dissimilar vessels in a comparative sense when the steam conditions, types or auxiliaries, boiler conditions, heat value of the fuel, and methods of heating the feed water, do not correspond on the ships being compared. Using such fuel rates as a means of bolstering up the presumed superiority of one type of propelling equipment over another, is often reduced to an absurdity when viewed in the light of pure thermodynamic analysis.

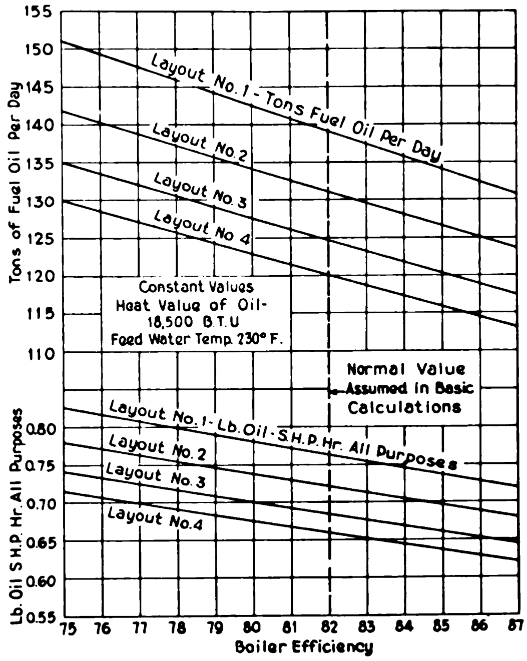


Fig. 5. Curves Showing Effect of Boiler Efficiency on Fuel Rates

It will be noted first, that, in the basic calculations, fuel rates of from 0.762 to 0.66 pounds per shaft horsepower-hour for all purposes were obtained by varying the initial steam conditions only, and secondly, that fuel rates of from 0.645 to 0.558 were obtained by applying additional economic measures and presuming the most favorable heat value of the fuel, boiler efficiency, vacuum, and operating conditions. In all the foregoing calculations the design characteristics of the main propelling equipment remained unchanged.

The all-electric ship made its debut into the large merchant ship class but little over a year ago, and the gap between the efficiency of power production in the modern central station and ship is being rapidly closed.

The Charles A. Coffin Fellowship Awards for 1929-1930

EIGHT fellowships have been awarded by the Charles A. Coffin Fellowship and Research Committee for the year 1929-30. These fellowships, which are awarded for one year, will enable the recipients to enter into, or continue, original research work at institutions of their own choosing. This makes a total (including renewals) of 55 graduate and undergraduate students who have held the fellowships since the establishment of the Foundation in 1922.

The purpose of the fellowship is to encourage research in electricity, physics, and physical chemistry on the part of students who are already engaged in such work and who, without aid, would be forced to drop or postpone their efforts with the results partially accomplished, and also those who feel that they have special aptitude for such work, but who hesitate to start on it when faced with the prospect of being forced to discontinue before they have reached whatever goal they have set.

The fellowships are awarded by a committee of three, representing three leading technical societies. The committee making this year's awards included: Gano Dunn, representing the National Academy of Sciences; R. F. Schuchardt, representing the American Institute of Electrical Engineers; Dexter S. Kimball, representing the Society for the Promotion of Engineering Education; and W. W. Trench, secretary of the Committee. Dr. W. R. Whitney, director of the Research Laboratory of the General Electric Company, who represented the company, worked closely with the committee.

The fellowships were awarded to the following:

Howard L. Andrews for research at Brown University on the measurement of dielectric constants at high frequencies. Mr. Andrews holds the degrees of Sc.B. and Sc.M. from Brown University, which he received in 1927 and 1928 respectively. At present he is an assistant in the Physics Department, Brown University.

Robert F. Bacher to continue research in the theory of spectra and its interpretation and connection to the subject of atomic structure. Mr. Bacher received a Charles A. Coffin Fellowship last year and will continue his work at the University of Michigan. He received a B.S. degree from the University of Michigan in 1926 and a similar degree from Harvard in 1927.

William M. Bauer is a graduate of Northwestern University Engineering School, receiving a degree of B.S. in liberal arts in 1927, and B.S. in E.E. in 1928. He is at present doing graduate work at Harvard Engineering School, where he will do research work in the fundamental theories to account for the behavior of dielectrics under high-voltage stress.

Vinton A. Brown for research in the development of improved methods in the measurement of x-ray intensities, with particular attention to the development of a method critically sensitive to rays of a certain frequency. Mr. Brown will receive the degree of B.S. in physics in June of this year at the University of Arizona, where he will do his research work.

Edmund A. Evans for research in the development of a theory of thunderstorms explaining (1) the production of cloud charges, (2) movement and concentration of cloud charges and (3) the nature, voltage, and mechanism of a lightning discharge. He received the degree of E.E. from Rensselaer Polytechnic Institute in 1925, and is at present employed as a student engineer of the General Electric Company. Mr. Evans was connected with the work of measuring lightning surges by means of a cathode-ray oscillograph conducted last summer on a 220,000-volt transmission line of the Pennsylvania Power and Light Company. He will do his research work at Leland Stanford, Jr. University.

Niels E. Edlefsen to continue his research work at the University of California in the photo-electric ionization of metallic vapors. He received a Charles A. Coffin Fellowship last year, and has been studying at the University of California. He graduated from Utah Agricultural College in 1916 with a degree of B.S., and received the degree of M.A. in 1923 from the University of California.

George R. Stibitz for research in theoretical physics along the lines of the field-quantum theory. Mr. Stibitz graduated from Denison University with a degree of B.S. in 1926 and received a M.S. degree from Union College in 1927. He is at present doing graduate work at Cornell University where he will continue his research.

Samuel B. Thomas for research in the physical properties of simple glasses, *i.e.*, boron trioxide with special regard to specific heats throughout the transition range. He graduated from Stanford University in 1928 with a degree of B.S. in chemistry, and received an A.B. in 1929. He has been doing graduate work at Stanford University, where he will continue his research.

LIBRARY SECTION

Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

Balancing

Balancing Rotating Units in Service. Peter Davey.
Mach., Mar., 1929; v. 35, pp. 532-535.
(Illustrated description of the "Vibroscope" portable balancing device for determining static and dynamic unbalance of machines without dismantling them.")

Converters, Synchronous

Safe Operation of Rotary Converters. R. E. Powers.
Power, Mar. 19, 1929; v. 69, pp. 470-472.
(Describes the apparatus necessary to protect the machine against dangerous operating conditions.)

Dielectric Phenomena

Anomalous Conduction as a Cause of Dielectric Absorption. J. B. Whitehead and R. H. Marvin.
A. I. E. E. Jour., Mar., 1929; v. 48, pp. 186-189.
(Abridgment.)

Electric Cables

Losses in Armored Single-Conductor Lead-Covered A-C. Cables. O. R. Schurig and others.
A. I. E. E. Jour., Mar., 1929; v. 48, pp. 206-210.
(Abridgment.)

Electric Signs

Survey of Neon Signs. H. A. Cook.
Illum. Engng. Soc. Trans., Feb., 1929; v. 24, pp. 133-143.
(A study of their power factor, wattage, and general performance.)

Electrical Machinery, Synchronous

Two-Reaction Theory of Synchronous Machines; Generalized Method of Analysis—Part I. R. H. Park.
A. I. E. E. Jour., Mar., 1929; v. 48, p. 194.
(Abridgment.)

Electricity—Applications—Domestic

Developing a Sound Policy for Water Heating. M. L. Hibbard.
Elec. West, Mar. 1, 1929; v. 62, pp. 137-140.
(Describes different types of domestic electric water heaters.)

Noises, Machinery

Study of Noises in Electrical Apparatus. T. Spooner and J. P. Foltz.
A. I. E. E. Jour., Mar., 1929; v. 48, pp. 199-202.
(Abridgment.)

Photometers and Photometry

Interlaboratory Comparison of Colored Photometric Filters. E. C. Crittenden and A. H. Taylor.
Illum. Engng. Soc. Trans., Feb., 1929; v. 24, pp. 153-207.

Radio Receivers

Aircraft Radio Receiver for Use With Rigid Antenna. F. H. Drake.
Inst. Radio Engrs. Proc., Feb., 1929; v. 17, pp. 306-319.

Railroads, Electric

Electrical Equipment Specially Designed for Philadelphia Subway.
Elec. Rwy. Jour., Mar. 9, 1929; v. 73, pp. 395-401.

Residence Lighting

Lighting the Home for Special Occasions. Lillian E. Eddy.
Illum. Engng. Soc. Trans., Feb., 1929; v. 24, pp. 117-132.

Steam Plants

Holland Station Design Embodies 1200 Lb. Pressure Features.
Power Pl. Engng., Mar. 1, 1929; v. 33, pp. 282-287.
(Describes equipment in a high-pressure station of the General Gas & Electric Corp. at Holland, N. J.)

Telemeters and Telemetry

Telemetering. C. H. Linder and others.
A. I. E. E. Jour., Mar., 1929; v. 48, pp. 183-185.
(Abridgment.)

Vacuum Tubes

Mechanism of Electron Oscillations in a Triode. H. E. Hollmannn.
Inst. Radio Engrs. Proc., Feb., 1929; v. 17, pp. 229-251.
(In addition to footnote references, contains a short bibliography, pp. 250-251.)

NEW BOOKS

(These and other Technical Books may be purchased through the Circulation Dept. of the GENERAL ELECTRIC REVIEW.)

Handbuch der Experimentalphysik. Vol. 13, Pt. 2. W. Wien and F. Harms (Editors.) 492 pp., 1928, Leipzig, Akademische Verlagsgesellschaft, m.b.H.

(This volume, which is one of a several-volume German encyclopedic work on experimental physics, is devoted to the thermionic tube, and provides a valuable addition to the literature on that subject. It consists of three main sections. The first, written by W. Schottky and H. Rothe, deals with the physics of the thermionic tube. Section two, by H. Simon, discusses the technical questions arising in the construction of electron tubes. Section three, contributed by H. Rothe, takes up the various kinds of tubes and their practical applications. The work brings together a great amount of valuable information hitherto scattered throughout the pages of numerous society transactions and trade papers. It forms an important contribution to the literature on the technical aspects of the thermionic tube.)

Industrial Carbon. C. L. Mantell. 410 pp., 1928, N. Y., D. Van Nostrand Co., Inc.

(This is one of the Industrial Chemical Monographs, which "are devoted to the practical treatment of specific products, processes and operations. They emphasize the scientific fact and its industrial applications without going exhaustively into the theoretical detail underlying the fact. Hence, their simplicity will appeal not only to the specialist but to the plant superintendent, salesman and others qualified to study working chemistry. . . In preparing this book, the author has attempted to cover the technologic applications of elemental carbon, aside from its use as a fuel. The term 'elemental carbon' is applied to mean those substances, materials and products which are either carbon in its elemental form, or which consist entirely of carbon, or whose value in industry is due to the physical and chemical properties of the elemental carbon from which they are made or which they contain. A chapter on charcoal as a fuel is included for reference in connection with the many applications of charcoal as an adsorbent. . . The contents of this volume fall naturally into several subdivisions—the truly elemental forms such as diamonds and graphites, with their industrial phases; carbon pigments and fillers, such as carbon black, lampblack and other blacks; absorbent carbon of the gas, decolorizing and metal adsorbent types, with which bone black is grouped; and the manufactured carbon products, such as electrodes, brushes, etc. A reference chapter on the physical characteristics of carbon is included." A subject index and an author index bring to a conclusion a useful volume on one of the more important materials of industry.)

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IN MEMORIAM

ASA F. BATCHELDER

1862–1929

GENERAL ELECTRIC
REVIEW

Vol. 32 July, 1929 No. 7

PIONEERS

We publish in this issue an address entitled, "Missionaries of Science," by Mr. E. W. Rice, Jr., which was read before the Stanley Club at Pittsfield. It always gives us pleasure to print what Mr. Rice writes about the pioneer days of our industry, as he himself is a pioneer of most of our other pioneers. Indeed, he and his life-long friend, Professor Elihu Thomson, might justly be called the Fathers of America's greatest and most progressive industry. They were both prominently instrumental in the creation of America's electric light and power business which they have had the extraordinary good fortune to see grow from its inception to its present staggering proportions.

We say America's light and power business rather than include the whole electric business, as we happen to have the figures for the light and power business for the year 1928 before us as we write. In that year the gross revenue from America's light and power business amounted to the tremendous figure of two billion dollars ($2,000,000,000). Professor Thomson and Mr. E. W. Rice, Jr., have also, since they were working together building their first arc-lamp dynamos, lived to see the electric light and power stations of America generate the fabulous total of sixty-nine billion seven hundred million (69,700,000,000) kilowatt-hours within a single year. These figures are in themselves astonishing, but perhaps it is even more astonishing to state that the total revenue from, and the number of kilowatt-hours generated by, the electric light and power stations of the United States doubled in the last six years.

When we realize the prominent part played by Prof. Thomson and Mr. Rice in this marvelous growth, their close connection with that great host of inventions and developments that have metamorphosed our industrial and social lives—and again their intimate connection with, and knowledge of, the many pioneers that brought these changes about —we wish that we could persuade them to write more for our columns about these pioneers and their work. There are none better fitted than they to tell this story for the benefit of posterity and the enlightment and encouragement of that host of young men who are dedicating their lives to the further upbuilding of our industry.

We add no comments to the tribute Mr. Rice pays to certain of our well-known pioneers, for the simple reason that we feel incompetent to do so. But the thought passes through our mind that if biographical sketches were written of all the best-known pioneers that have made notable contributions to our electrical industry, how incomplete the story would be. There are some—nay—there are many pioneers—a great host that would forever remain unsung.

There is perhaps no class of men, speaking of the engineering world, for whom we have greater respect and admiration than that great army of fine old mechanics in our workshops. Their contributions have been legion—how many a device has been made operative by their skill! How many an unrecorded invention have they contributed to our welfare! But that is a story that will never be written for the simple reason that no one knows it; but we do know that many a pioneer has done his life's work at the bench.

Another tribute to our blacksmiths, mechanics, machinists, and artisans of all classes. They have given us more than their skill and faithful service— they have given us their sons. It is the use of the hands that develop our cerebral cortex—the seat of human intelligence in the brain. How many more great scientists, engineers, inventors, and pioneers have been given us by our artisans than by our kings and dukes and "armchair" ancestors.

And again in a higher (?) station, how many engineers, that the world at large knows nothing of, have made notable contributions to our modern advancement! There are some that receive the plaudits of the crowd. There are many more that do not. How many an engineer—how many a really great engineer in his particular field, whose work does not necessarily appeal to the public imagination, lives his life, makes his great contribution, and passes on unknown!

These thoughts come to our mind as we mourn the death of a friend who was a great engineer in his own particular field and of whose work the public knowns little. We refer to A. F. Batchelder who passed away on May 20, 1929.

We feel that Mr. Batchelder can be taken as a typical example of a multitude of great men that

American institutions have developed and whose work has enabled other pioneers to build up the United States from small beginnings to the proud position it holds in the world today. There has been no more rapid development in the world's history than that of the United States of America in the last hundred years. And this great development has been brought about largely by the innate skill, ingenuity, engineering ability and—above all—by the perseverance and character of a great host of men who have made notable contributions to our progress and passed on almost unremembered.

As our tribute to the memory of A. F. Batchelder, we publish, with affection and respect, his portrait as our frontispiece this month.

Asa F. Batchelder was born at Levant, Maine, on March 10, 1863. He was with the Thomson-Houston and the General Electric Company for a period of 36 years, retiring in 1925 because of ill health. It was in the year 1889 that he entered the service of the Thomson-Houston Company at Lynn where at one time he was foreman of the Commutator Department. In March, 1894, he came to Schenectady, where the railway work of the General Electric Company had been centralized. In August, 1897, he was appointed by W. B. Potter, Engineer of the Railway Engineering Department, to assist E. D. Priest in the Railway Motor Department; and when in February, 1912, the Railway Locomotive Engineering Department was formed he was placed in charge, a position he held until his retirement.

He was recognized by all with whom he came in contact as a man of great originality and sound engineering judgment. He has to his credit 113 patents as an eloquent testimony of his inventine genius.

The creation of old "6000," the original high-speed passenger locomotive for the New York Central electrification is an example of his instinctive engineering ability and knowledge. Further, he possessed the courage and determination to put over such a radical departure from the commonly accepted designs. Utilizing the mechanical structure of the locomotive as the magnetic circuit, he mounted the motor armatures directly on the driving axles and achieved a sturdy, simple construction that has proved conspicuously successful in hauling millions of passengers in and out of the New York Central Terminal during the last twenty years.

Batchelder's locomotives are in successful operation upon the electrified tracks of many railroads. The Great Northern, electrified in 1908; the Butte, Anaconda, and Pacific in 1912; the Chicago, Milwaukee, St. Paul and Pacific in 1915; the Paulista Railway, The Spanish Northern, the Mexican Railway, the Bethlehem Chili, the Detroit Tunnel of the Michigan Central Railroad, and the Canadian Northern at Montreal—all bear tribute to his rare engineering ability.

It is not our intention at this time to write an extended account of his work; we merely put on record the simple fact that we shall miss him and that we always regarded his work with admiration and himself with affection. J. R. H.

Missionaries of Science

By E. W. RICE, Jr.
Honorary Chairman of the Board, General Electric Company

(Address delivered at the Stanley Club of the Pittsfield Works on Monday, May 13, 1929)

MY early life was spent among missionaries. At the time of my birth my father was a missionary, preaching the gospel and founding non-sectarian Sunday Schools in the then pioneer territory bordering on Wisconsin and Minnesota.

My mother's sister married a missionary, and, as my mother died when I was an infant, my earliest recollections are of the missionary home of my aunt in Red Wing, Minnesota.

Now, I do not remember meeting a single long-haired, sour-faced fanatic—the type which many associate with the calling. On the contrary, they were cheerful, quiet, modest men, filled with the desire to be helpful. Many were from the East, and had started in life as ministers, lawyers or merchants. Migrating west, however, they bravely endured the countless hardships of a pioneer life, not only because of a desire to aid and comfort their less fortunate fellow men, but, as I suspect, because they possessed the adventurous nature of the pioneer and could not help answering the call of the wilderness with its broad prairies, myriad lakes, mighty rivers, and deep green woods. They were trail makers and enjoyed lending a helping hand to the pioneer in his sturdy effort to subdue the land and to extend the boundaries of civilization.

To me, the spirit of the missionary and the spirit of the pioneer are much alike. It is the spirit which seeks to banish ignorance, which rejoices in overcoming obstacles, which makes light of hardships, and is inspired by something finer than the desire for fame or power or money.

Perhaps because of such early influences, it was natural for me to recognize and welcome those other pioneers, the missionaries of science whom it was my good fortune to meet a few years later, and with whom it has been my privilege to be associated all my life. It is of a few of these noble spirits and of their work and influence that I wish to speak to you this evening.

I shall speak first of one who has been my lifelong friend, Elihu Thomson.

Professor Elihu Thomson

I regard it as the most fortunate event in my life that I met Elihu Thomson when I was young. I was but a boy in my teens when we met in the Philadelphia High School in 1876. He was still a young man of but 23, although already recognized as a brilliant teacher with a growing reputation as a lecturer and scientist.

His intense interest in science, his eagerness to help all those who showed the least desire to acquire information, soon brought us together. I was fortunate enough to interest him in my efforts to make a telescope. Being too poor to buy one, I had resolved to build one and had read all I could find on the subject. An achromatic refractor seemed hopelessly beyond my skill and purse, so I had decided upon a reflecting telescope. The problem was the making of the mirror, which I assumed must be of speculum metal. As Professor Thomson was a chemist, I thought he might be willing to tell me how to make the proper alloy, and so, rather hesitantly, I presented my problem.

I shall never forget his cordial response. He acted as if the problem were of the utmost importance and of great personal interest. To my delight, he said that he too had made a telescope and had also decided upon the reflecting type, but that speculum metal was no longer used, as a mirror of glass was much better.

He then told me that he had devised a new and simple way of making a glass mirror without machinery and without moulds. It was only necessary to take two pieces of plain plate glass, about ½ inch in thickness, cut them round, then to fasten one piece to the top of a table, cement a wooden handle to the second piece, secure some emery and water and start the grinding process. By simply moving the top piece of glass back and forth in every possible direction over the lower piece, the surface between would assume a true spherical shape. The longer one ground, the shorter became the radius of curvature, so that it was possible to produce any desired focus for the mirror. The upper glass would become concave, and the lower convex. If it happened that the grinding was carried too far and the focus thus became too short, it was only necessary to reverse the process by exchanging the positions of the upper and lower glasses. He demonstrated the theoretical correctness of the process, and stated that the only geometrical form that could result from such a process was a section of a perfect sphere. The process was so ridiculously simple as to be incredible, but I went ahead, and by following his instructions, eventually succeeded in making a satisfactory glass mirror for a small telescope. It took many interviews and much patience on the part of Professor Thomson before the work was finished to our mutual satisfaction.

Alexander Graham Bell had but recently invented the speaking telephone which was first shown publicly at the Centennial Exposition in Philadelphia in 1876.

I soon found that Professor Thomson had made some telephones which he was good enough to show me. It was my first acquaintance with this latest marvel of science. Naturally I wanted to own one, so, along with another boy friend, I started to make a pair.

Professor Thomson gave me advice and help as cheerfully and patiently as in the case of the telescope. This was my introduction to electricity, and was the occasion of many more thrilling interviews after school with Professor Thomson while I was making the telephone at home, and afterwards while making other electrical devices such as static machines, electric batteries, induction coils, and finally a small dynamo. For the dynamo, Professor Thomson told me of his own three-coil armature machine just invented, and with his help I constructed a small working model.

The events which I have briefly sketched cover the years while at high school, up to the winter of 1879–80. It was during this period that Professor Thomson, as stated, invented his three-coil arc dynamo with automatic regulator, and automatic arc lamps, made the famous Franklin Institute test on the Brush and other dynamos, delivered lectures at the Franklin Institute, besides faithfully discharging the duties of teaching chemistry and physics to large classes of students.

During the spring of 1880 he organized the American Electric Company of New Britain, Conn., to manufacture and sell his inventions and those of his associate, Professor Houston. In July, 1880, he left the high school and started on his independent career as electrician of the American Electric Company, afterwards called the Thomson-Houston Company.

There followed a period of intense inventive activity and rapid technical progress. During the next decade he invented the air blast insulation for commutators, magnetic blowout switches, lightning arresters, the oil-cooled and oil-insulated transformer, electric welding, a single-phase repulsion motor, a high-frequency transformer, electric meters and instruments,—to mention but a few of the inventions and discoveries which have given him a secure place in the electrical Hall of Fame.

But it is not my object to tell the story of these developments. *I prefer to trace as briefly as possible his connection with the evolution of the alternating-current transformer system, a complicated tale which has never been fully told, embracing many places, and including many actors.*

But first I will digress to tell of an incident of a later period, one connected with the electrical development of Niagara, in which two of the world's greatest physicists came together to consult our Thomson at Lynn.

Lord Kelvin and Professor Henry Rowland

The visitors were Lord Kelvin and Professor Henry Rowland. They were members of a committee which had been appointed to decide upon the development of the power of Niagara Falls, and I believe that the decision to use three-phase, 25-cycle current had already been reached. They were desirous of ascertaining the practical limits, particularly in size, of transformers and motors.

I remember they asked us what was the largest size of transformer which we would guarantee to manufacture in the near future. Now, the largest transformer in regular production at that time was rated at 150 lights; that is, about 7.5 kw. output. After considerable discussion, we replied that we were prepared to make transformers of 100 kw., which seemed to us a tremendous step! It was apparently entirely satisfactory to Kelvin and Rowland.

A few years later Lord Kelvin visited Schenectady and we were then able to show him transformers of 1000 kw. A year or two later, while in London, I called upon Lord Kelvin. He immediately inquired what progress had been made in size, voltage, and efficiency of transformers in America. When I started to reply, he said, "Wait a minute please," and to my astonishment, he went to his desk and produced a notebook, from which he read to me the information which I had given him on his visit. Now he asked, "What has happened since," and took out his pencil. I have forgotten my reply, but I gave him the required information, in which he seemed deeply interested, and of which he made notes. I mention this as an illustration of one of the characteristic methods of this great man.

I do not need to remind you that Kelvin was the man who turned the Atlantic cable from a failure to success by his mathematical analysis of the technical difficulties of transmission and by his invention of the siphon recorder; that at the time the Kelvin (Thomson) galvanometers were the world's standard, and that he was regarded as the world's leading physicist and mathematician. Yet he was not afraid to ask questions from anyone whom he met, young or old. He was on the constant lookout for facts and made notes of any new facts that came his way.

You may also remember that he was one of the committee of experts at the Centennial of 1876, before whom Bell demonstrated his telephone, and he was quick to appreciate the marvelous character of that invention. He was equally enthusiastic over the simplicity and usefulness of Edison's incandescent lamp.

Like Edison, however, he was slow to admit the limitations of direct current, or to foresee the great possibilities of alternating current in the generation and transmission of electrical energy.

He was altogether a delightful personality, modest in spite of his great achievements, and generous and quick to appreciate the talents and work of others.

Professor Rowland, his companion at the time of the visit to Lynn, was the head of the Physical Laboratory at Johns Hopkins University, and I do not need to remind you that he was already famous for the design and manufacture of the most perfect optical gratings, for the invention of the concave grating, for the most complete photographic map of the Solar Spectrum; and in electricity, for his marvelous demonstration of the magnetic effect of moving electrostatic charges.

He was indeed a great experimenter, marvelous mechanic, and one of the world's greatest physicists. However, he did not possess the modest bearing of Kelvin. He was nervous, impatient, and shocked those who did not know him well by his self-confidence and frank pride in his accomplishments. However, he was one of those rare men who, notwithstanding his unconscious egotism, was truly great.

First Induction Coils Operated as Transformers in 1879

Returning now to my story of Professor Thomson's connection with the evolution of the alternating-current transformer system. You may remember that at the Franklin Institute lecture in Philadelphia in the winter of 1879, Professor Thomson showed a 2-phase, self-exciting alternator of his own design; that one of his experiments was to connect this alternator to two induction coils, the primaries of which were connected in parallel, and from the secondaries of which current was supplied to operate his little vibrating arc lamp. So far as I can ascertain, this was one of the earliest instances in history in which induction coils were operated by an alternating current to step down the voltage and to increase the current. Also, it was apparently the first time that such induction coils were actually operated with their primaries connected in parallel from an alternating-current dynamo.

These induction coils were also notable for being constructed with a closed magnetic circuit instead of the open magnetic circuit commonly employed.

The strenuous work of developing commercially the arc light system occupied all Professor Thomson's time and energy for the next few years after his removal to New Britain. However, his mind constantly reverted to those early Franklin Institute experiments, and he frequently told me that they ought to be taken up and more work done along those lines.

When in 1883 Gaulard and Gibbs brought out their induction coil system, there was general skepticism in the electrical world as to the efficiency of the induction coil. However, Professor Thomson was firm in his belief that the induction coil was efficient and useful for changing the voltage and the current, and so stated to me on many occasions at the time.

He said so much about the value of his induction coil system, that for my own satisfaction, in January, 1884, I made some sketches, in which the primaries of induction coils are shown connected in multiple on a constant potential alternating circuit. Under the sketch I wrote: "Induction coils in multiple arc, for economy use high resistance primary, although dangerous." The sketch shows the primary coil with many turns of fine wire, as contrasted with the secondary, of a few turns of much coarser wire.

Evidently the matter was being discussed a great deal between Professor Thomson and myself because (on June 11, 1885) eighteen months later, I made another sketch, showing transformers operating in parallel, under which was the following note in my handwriting: "The idea is to use a reversed current generator of constant potential, feeding the mains. Between these mains are connected induction coils, the secondary coils of which are used to work small lamps. Action is as follows: When coil is connected so that current passes through the primary and the secondary is open circuited, the reactive kick of the primary will be at its maximum and scarcely any current flow. When the secondary circuit is closed through a resistance, (as the lamp) the reactive kick of the primary lessens, more current flows in consequence, and more energy is hence consumed and given out. The whole system is hence self-regulating in every respect."

During the year 1885, I remember that Professor Thomson made several experimental runs with transformers whose primaries were connected in parallel, and with incandescent lamps (Woodhouse & Rawson) operated from the secondaries. In the early part of 1886 Professor Thomson built another alternator, and in the fall of that year, made an installation of about twenty 50-watt lamps in a new factory, called Factory B.

On September 2, 1885, Professor Thomson made application for a patent which fully described this system, and from which I quote briefly as follows:

"My invention consists in a novel system of electrical supply, comprising in combination electric mains furnished with alternating currents of comparatively high potential, a set of induction coils being placed with their primaries connected at intervals with the mains so as to be in multiple arc with one another, and secondary coils or circuits connected to local circuits and properly proportioned to obtain the desired induced electric energy for operating electric lights, motors or other devices." The three claims of the patent fully cover the invention.

Unfortunately this application was delayed in the Patent Office seventeen years, through no fault of Professor Thomson, and was not issued until April 22, 1902. The delay in the issue of the patent was largely caused by numerous interferences in the Patent Office, in which the names of Brush, Halleck, Hunter and Freeman appear as contestants. However, the issues were finally settled in favor of Thomson, and the patent issued in 1902.

Litigation for its enforcement against infringers was instituted by the General Electric Company in 1903, and after many years, on April 18, 1913, the patent was declared invalid by the Court.

While interesting history, it would take too long to quote the decision in full, but, briefly, the Court found: That Thomson failed to show reasonable diligence in reduction to practice; that prior publications existed; that many others were experimenting and theorizing during this same period; that Jablochkoff described in 1877 everything excepting the multiple arc connection of transformers; that the Brush patent of September 2, 1879 showed the same thing, although not claiming it; and lastly, because of patentee's general delay; the Court having in mind evidently the delays in the Patent Office and the delay in diligently prosecuting litigation after the patent was issued.

I have gone into Thomson's development of the alternating-current potential transformer system at some length because it is part of the history of a development of extraordinary interest, which was, and remains of fundamental importance to our industry.

It also gives me an opportunity to speak of another of those great missionaries of science, to whom the world is so greatly indebted. I refer to William Stanley.

William Stanley

My first recollection of William Stanley was on the occasion of a visit which he made to New Britain sometime in 1881 or 1882. He ostensibly wished to interest Professor Thomson in his new filament for incandescent lamps. It was also evident that he wished to become personally acquainted with Professor Thomson whom he recognized as a fellow worker. I do not remember the conversation, but still retain in my memory a vision of Stanley at that time: young, eager, enthusiastic, vivacious, he left an impression of a lively and altogether lovable personality.

About this time (1881) Stanley was working as first assistant to Mr. Hiram Maxim, another famous missionary of science, who has left the following interesting word picture of Stanley:

"At that time (1881) Mr. Stanley was very young; he was also very tall and thin, but what he lacked in bulk he made up in activity. He was boiling over with enthusiasm. Nothing went fast enough for him. Whatever was given to him to do, he did it in the most thorough manner. He spared no trouble or expense, often spending his own money for material which he thought better than that which was available in the Works."

Our paths did not cross again for several years. When we heard that Stanley had developed a new alternating-current system for lighting by the use of induction coils or converters, we were sure that it would be interesting. When later we learned the nature of the system, we recognized it as similar to that upon which Professor Thomson had been experimenting.

My time was so absorbed in helping Professor Thomson at Lynn that it was naturally impossible to gain at the time an entirely clear idea of Stanley's work. However, later on, from conversation with Stanley, from his letters, published articles, patents, etc., I was able to obtain what I believe to be a connected, and susbtantially correct picture.

Evolution of the Commercial Transformer

It would appear that in the summer of 1883 he experimented with induction coils and observed that the value of the current flowing through the coils was not in accordance with Ohm's law, and reasoned that a counter-electromotive force was developed in the coil. He made sketches in a record book at the time. In the spring of 1885 he was working at Pittsburgh, and states that he then conceived the idea of so proportioning the converter as to secure a variation of the counter-electromotive force in the primary proportional to the current extracted in the secondary, and explained his idea to several persons and illustrated such explanations with experiments. He constructed several so-called reducing converters (transformers) to operate incandescent lamps, and in September, 1885, set up several of these reducing converters in multiple arc and ran them experimentally for several weeks.

Historic Removal to Great Barrington

Then comes the historic removal to Great Barrington. But meantime he was experimenting on the construction of his converters, and particularly those made with cores of thin iron plates. Several such converters were made in Pittsburgh late in 1885 and in January, 1886. Afterward such converters were made in Great Barrington up to July, 1886.

In March, 1886, he erected an experimental plant at Great Barrington, in which he had seven converters arranged in multiple arc and supplying over 100 lamps, having a capacity of about 16 candle-power. This plant was started on March 16, 1886, and continued to operate successfully until June 17, 1886.

Mr. George Westinghouse, for whom he was working, and whose Company became the owners of his inventions in this line, was greatly impressed with the value of his work and began immediate preparation for the manufacture and commercial exploitation of his system, and in November, 1886, erected an installation at Buffalo which was put into operation about Thanksgiving Day in that month.

For some reason, with which I am unacquainted, Stanley failed to file an application for his system until August 15, 1888, a delay of over two years, and his patent was issued in March, 1892.

Stanley's claims in his patent application of 1888 were not so broad as the Thomson application of 1885. It is true that the diagrams looked alike and that both purported to cover a constant potential system of electrical distribution in which transformers were connected in parallel across the mains of an alternating-current circuit, the secondaries of which were used to operate incandescent or other electrical devices.

But Stanley also adds in his description a statement, or rule for the design of a transformer, substantially as follows: "The first thing to be determined is the length of the primary wire. This should be of such length that, reacting self-inductively upon its own magnetic circuit, the average counter-potential so produced approximately equals the potential applied to the primary circuit. When so constructed, an ammeter will show practically no current when the secondary circuit is opened."

This patent was also in litigation, and on April 27, 1901, the United States Court finally decided that this, the so-called "Stanley rule" feature, was new, and sustained the first and third claims. The suit was brought by Westinghouse against the Saranac Lake Company, whose real defendant was the Stanley Company of Pittsfield, who were then manufacturers of transformers. The Court decided that the patent was not anticipated by the publication of an article in the *London Electric Review* of August, 1885, describing the Zipernowski and Deri plant at Budapest, on the theory that the Court's inquiry must be confined strictly to the published article; that the question was not what was *actually* done at Budapest but what the article *said* was done there. The law provides that an inventor shall not be denied a patent because the invention was known or used in a foreign country. It must have been known or used by others in this country, or patented or described in a printed publication in this country, or a foreign country. The mere assertion that the desired result has been accomplished, without describing the means which produced the result, is insufficient. The Court also decided that the installation in Great Barrington which was made about two years and five months prior to Stanley's application for a patent, did not constitute a public use in the United States, as that installation was distinctly experimental. This was fortunate, as two years' public use would have invalidated the patent.

The commercial introduction of the constant potential alternating-current system with transformers followed promptly upon Stanley's demonstration in Great Barrington in March, 1886. This may be said, therefore, to mark the beginning of the commercial development and practical use of that system in this country.

It is true that Thomson and his co-workers knew nothing of the Stanley rule for design of transformers, above quoted, until the issue of his patent several years later in March, 1892, yet meanwhile they had made many thousands of commercial transformers.

It is my belief, however, that Stanley was the first to make a closed magnetic circuit transformer in which the magnetic material consisted of thin laminated-iron plates. Such was the construction of the transformers of the Great Barrington demonstration.

Naturally, during the intervening years the transformer has been greatly improved in mechanical design, in the quality of the sheet iron or steel, in the nature of its insulation, in its ventilation, in use of oil for insulation and cooling, and other important features—contributions of many able engineers, a number of whom are present this evening.

However, I think that there will be universal agreement with the view that the Stanley converter of the historic Great Barrington experiment was the prototype of, and contained the essential elements of that amazing and most nearly perfect of all electrical devices—the modern transformer.

Stanley is also to be given credit for designing the first commercial constant-voltage alternating-current dynamo, whose manufacture was continued for a number of years.

"Stanley Deserves Credit of Being Independent Inventor"

I am glad to say that I think the record fully justifies the statement that, irrespective of the work of Professor Thomson in Lynn or of Zipernowski and Deri in Budapest, William Stanley deserves the great credit of being considered as the independent inventor of the system which I have described; and even more, that it was due to his imagination, courage, perseverance, energy, and inventive ability that the system was reduced to practical operation and started on its commercial career at that time. Much credit belongs to Mr. George Westinghouse for the energy and enthusiasm with which he took up the manufacture and commercial exploitation of the Stanley system.

It may be asked why Thomson so long delayed in reducing to practical form his constant potential transformer system. He had the advantage of early conception of the idea, and of the first actual experimental demonstration. It was the subject of frequent discussion with his assistants. He had a clear understanding of the properties of induction coils and believed in their efficiency, understood the self-regulating quality of the parallel connection, and thoroughly appreciated the importance of high voltage for low-cost and high-economy distribution of electrical energy over long distances to large areas.

The answer is not simple. It never is in such instances, as there were a number of reasons. One reason was his fear of danger to human life in case the insulation should prove defective between the primary and secondary circuit of a transformer. He mentioned this many times, and studied the solution earnestly. He reached a solution in the grounded secondary and in other methods in 1884-5. However, the underwriters of the insurance companies objected to the grounded secondary and would not give their consent to its use, and his other safety devices did not seem to him to give that absolute protection which he sought and considered necessary.

Another cause for delay was to be found in the incandescent lamp situation. Edison had invented the incandescent lamp and had obtained a patent which Thomson's patent adviser, F. P. Fish, assured him was fundamental and should and would unquestionably be sustained by the Courts, so that it would be unwise to infringe it. It was only after several years had passed and the apparent neglect of the Edison Company to stop infringers was so evident that the Thomson-Houston Company finally decided to manufacture incandescent lamps, so as to have an independent source of supply of lamps for a time at least. This manufacture did not begin until 1896.

Another cause was Thomson's complete absorption in his arc lamp and dynamo business, and his own tremendous fertility of ideas pressing for expression during the decade of 1880-90.

The combined effect of all these deterrent influences were, I believe, sufficient to account for his failure to push his ideas with his customary energy.

Great Inventions Arise Simultaneously

The history of the development of the alternating-current transformer system is an excellent illustration of the fact which has been often observed, that great discoveries or inventions often appear to arise almost simultaneously in different places in the world, the undoubted original productions of different minds. In fact, so common is this occurrence that about the only notable invention whose authorship I have never heard disputed is that of the speaking phonograph of Edison.

It is very difficult for one who possesses the knowledge and point of view of his own time to place himself in the position of those who preceded him and who only possessed the knowledge and point of view of their time.

The *London Electrician* of March 5, 1886, in an editorial referring to the experimental installation of Gaulard and Gibbs' system in Bond Street, London, makes the statement that: "the regulation is very poor and at times disastrous to the lamps." Then goes on to state that "Ferranti has lately been placed in charge and advocates a new transformer system with a parallel system of primary conductors . . . . . It seems to us that with parallel conductors the transformer system is robbed of the very advantages which make it of value, since the coefficient of transformation is brought down to 200/100, equal to 2, the limit of 200 being the electro motive force which can, by the Board of Trade regulations, be allowed between two points in a building. It surely is not proposed for one moment to work a parallel system where the primary has a difference of potential of 2000 volts. Not only are the risks of breakdown increased with parallel connections, but the briefest examination shows the proposal to be so absurd that we hesitate to believe it has ever been made."

Stanley, the Inventor and the Man

Some years after the events above related, William Stanley became associated with the General Electric Company, and it was my great privilege to see much of him during the last years of his life. Although troubled with ill health, he was remarkably industrious and persistent in his work. He took a lively interest in the many problems which the General Electric Company's activities presented, and we greatly enjoyed having him as a member of our research council. His enthusiasm was contagious, his questions searching, and his observations and suggestions were most stimulating and valuable. But he was happiest when at work upon some problem which he made his own, and we were glad to furnish him with facilities to develop his ideas.

He made valuable contributions to any subject to which he devoted his attention, and particularly to the art of domestic heating. He also invented a new thermos bottle, made entirely of metal, which required original research and the solution of many difficult mechanical problems.

His free-hand sketches were works of art, and made with a rapidity which was amazing, and left nothing to be desired in clearness of presentation.

He has been well said that "he made the workshop his university, and himself his own most competent teacher." He always retained his position among the foremost electrical engineers, and in 1912 received from the A.I.E.E. the Edison Gold Medal, the highest honor attainable in this field, the citation of the award reading: "For meritorious achievement in invention and development of alternating-current systems and apparatus."

He was gifted with rare aesthetic taste, as was shown in the beautiful homes which he built or remodeled. He was a delightful and generous host. This old world was a fairyland to him and he was happily blest with an ideal family life.

I came to respect his sterling qualities, and to have an ever-increasing affection for his lovable character. He possessed, even in his later years, the same brilliant, impulsive, generous nature that made such a vivid impression at our first meeting, thirty years earlier.

Other Missionaries of Science

I regret that time will not permit me to relate any of our experiences with many other missionaries of science of this period, notably Bell, Brush, Edison, Weston, Wood, Vandepoele and Sprague. These pioneers were then at the peak of their creative power. They had the courage and audacity of youth. Edison was but 32 when he invented the incandescent lamp; Thomson about 30 when he finished his arc lighting system; Stanley about 28 when he made the Great Barrington demonstration; and Bell was but 28 when he invented the telephone.

The period of which I have spoken was some years before the appearance of Steinmetz and of Moody, and was prehistoric times to Whitney, Coolidge and Langmuir, whose appearance ushered in our modern period.

I cannot close without mention of the debt which we owe to Stanley for his discovery and gift to us of his disciple and much-loved friend, whom we were so glad to welcome into the General Electric family—our own brilliant Faccioli.

I must also keep you long enough to pay my tribute to Stanley's most able assistant and co-worker, upon whose good judgment, technical skill and executive ability he leaned so heavily; one who since he entered our service has done his work so well that he has become the valued and popular head of our manufacture, our vice president, C. C. Chesney.

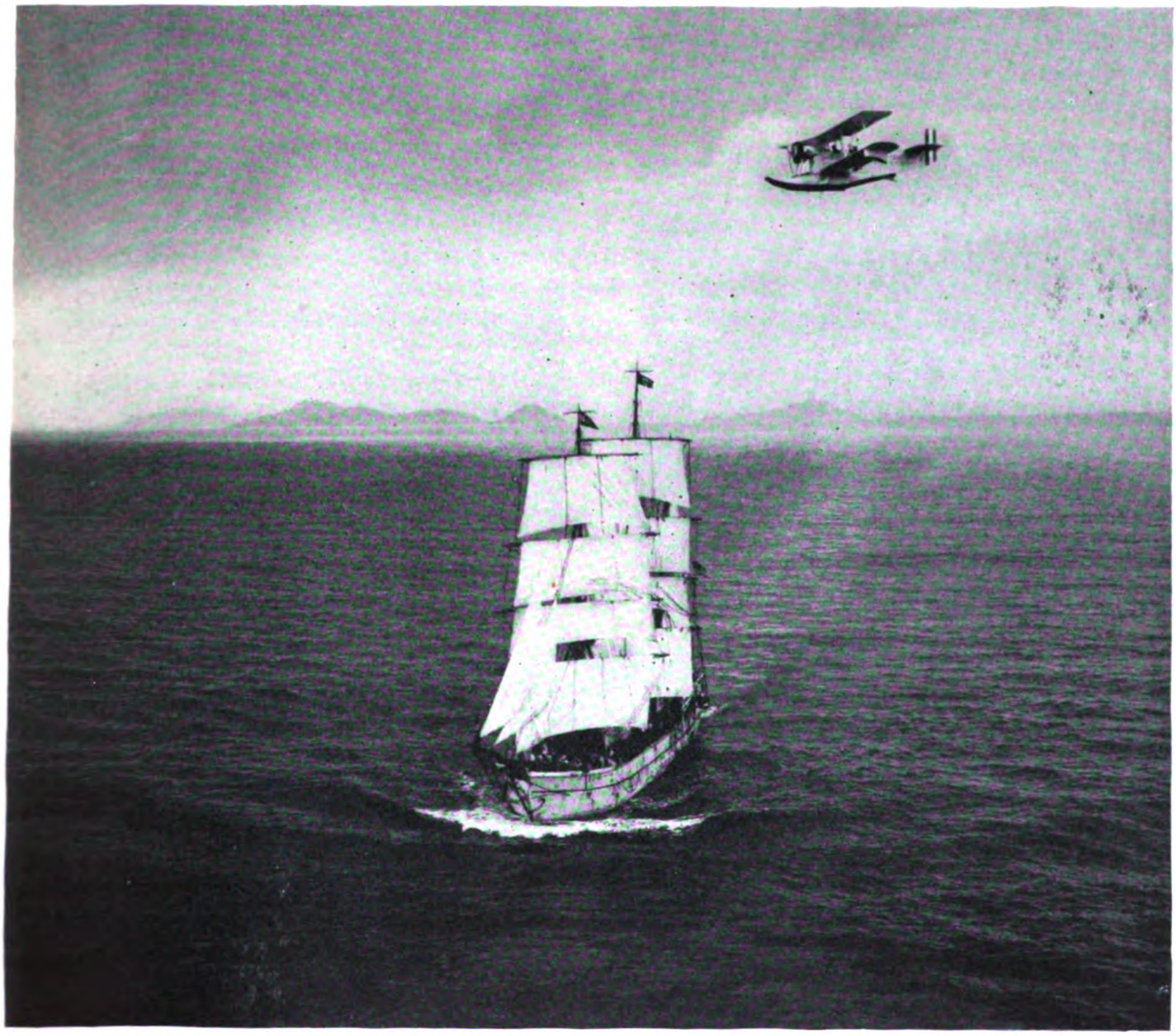


Photo by U. S. Marine Corps, Aviation

Whether it is Byrd sailing away for the Antarctic, or another daring adventurer sailing into some uncharted region of the sky, or a Missionary of Science working in an unknown field of Nature's extensive realm, the urge that leads them on is told in Kipling's "The Explorer":

Till a voice, as bad as conscience, rang interminable changes
On one everlasting whisper, day and night repeated; so . . . .
"Something hidden. Go and find it. Go and look behind the ranges.
"Something lost behind the ranges. Lost and waiting for you. Go!"

Shadow Pictures Illustrating the Magnetic Fields in Induction and Synchronous Motors

By **GEORGE K. PARMAN**
Omaha, Nebraska

It is always useful to be able to visualize electric and magnetic phenomena. So we feel that Mr. Parman's clever little models and their shadows will prove both instructive and interesting to many of our readers.—EDITOR

TO illustrate the magnetic fields in induction and synchronous motors the writer has made two rough wire models as shown in the illustrations.

The model in Figs. 1, 2, and 3 is to show the magnetic fields in the gap of a 2-phase 4-pole motor, and the model in Figs. 4, 5, and 6, in a 3-phase 4-pole motor.

As we place the models with their axes perpendicular to sun rays, or artificial light rays, and rotate them, the shadows, as seen in the foreground, between lines *a–a*, in Figs. 2, 3, 5, and 6, give us a moving picture of the magnetic stationary fluctuating fields and their resulting rotating field in the gap during the cycle.

The models are practically self-explanatory. The axis represents the circumference in the gap of a 4-pole motor and the models are based on the assumption that the intensity of the stationary fluctuating magnetic fields along the circumference, in the gap, due to each phase, is given by the ordinates of a sine curve. The

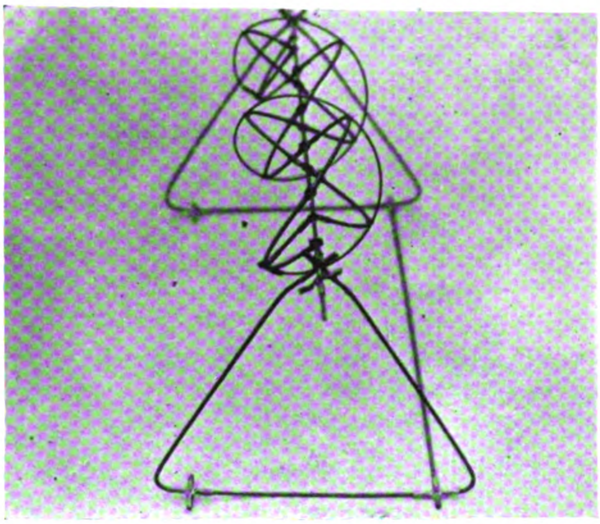


Fig. 1. Wire Model for Showing Magnetic Fields in the Air Gap of 2-phase 4-pole Motors

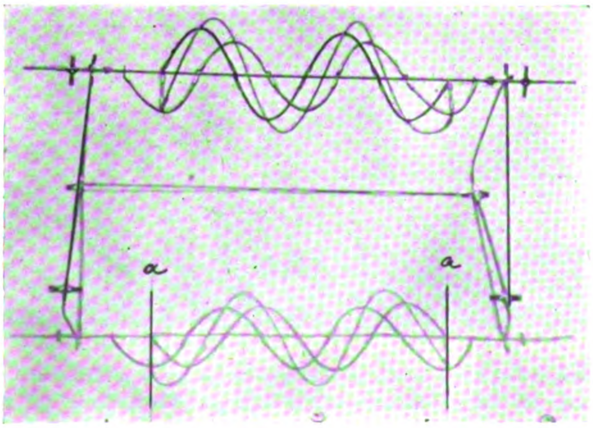


Fig. 2. Same Model as in Fig. 1, Showing (Between the Lines *a–a*) Shadow Moving Pictures of the Magnetic Stationary Fluctuating Fields and Their Resulting Rotating Field, in the Gap, During a Cycle

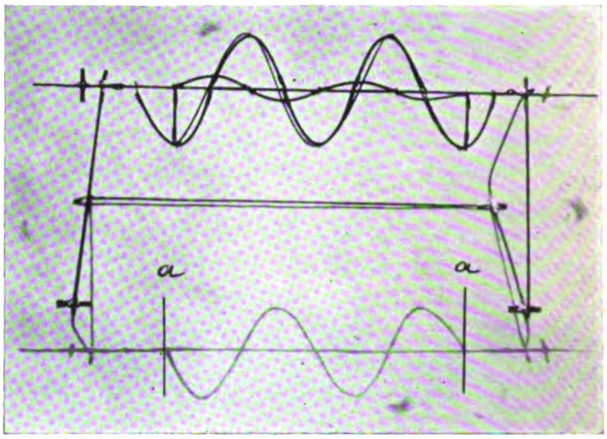


Fig. 3. Same Model as in Figs. 1 and 2, Showing (Between the Lines *a–a*), Shadow Moving Pictures of the Magnetic Stationary Fluctuating Fields and Their Resulting Rotating Field, in the Gap, During a Cycle

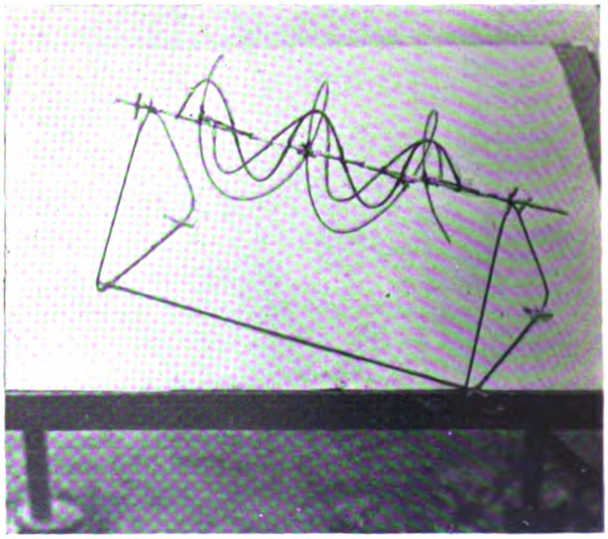


Fig. 4. Wire Model for Showing the Magnetic Fields in the Air Gap of 3-phase 4-pole Motors

models have, therefore, for each phase, a sine curve consisting of two loops above and two below the axis to represent the 4-pole motor.

In the 2-phase model, the second sine curve lies in a plane at 90 deg. to the first and 90 deg. relative to each other, along the axis, assuming 180 deg. from pole to pole.

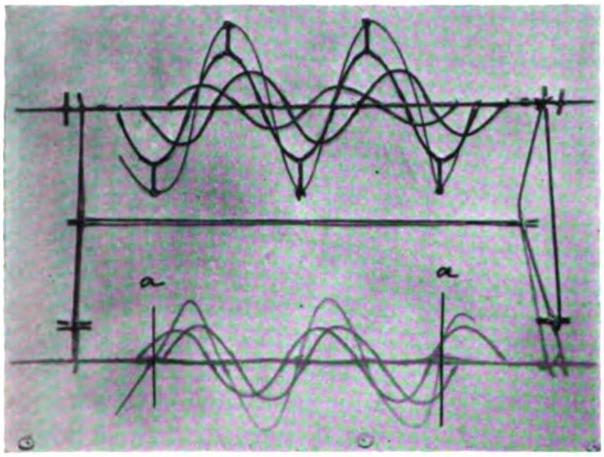


Fig. 5. Same Model as in Fig. 4, Showing (Between the Lines *a–a*) Shadow Moving Pictures of the Magnetic Stationary Fluctuating Fields and Their Resulting Rotating Field, in the Gap, During a Cycle

In the 3-phase model, the three sine curves lie in planes 120 deg. apart and 120 deg. relative to each other, along the axis, assuming 180 deg. from pole to pole.

These sine curves are the heavy wires. The shadows of these curves give us the stationary fluctuating fields. The resulting rotating field is obtained by the shadow of a spiral formed of the thin wire.

In the 2-phase model, the radius of this spiral equals the maximum ordinate of the sine curve; in the 3-phase model, one and one-half times the maximum ordinate.

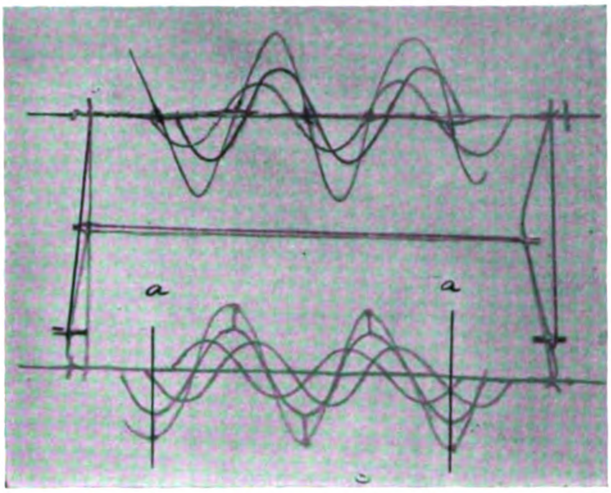
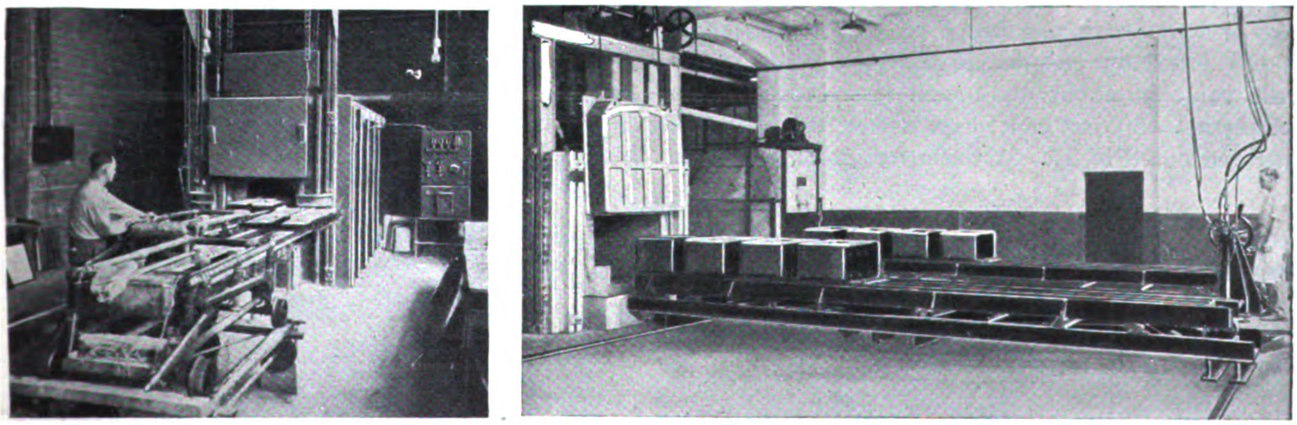


Fig. 6. Same Model as in Figs. 4 and 5, Showing (Between the Lines *a–a*) Shadow Moving Pictures of the Magnetic Stationary Fluctuating Fields and Their Resulting Rotating Field, in the Gap, During a Cycle

The models are quite easy to make. Here, slight errors will be noticed in the shadow pictures; they are entirely due to the models being only roughly made.

The moving shadow picture gives a very clear conception of the magnetic fields during the cycle and shows very well that the stationary fluctuating fields result in a rotating field.

Electric Furnace for Vitreous Enameling



Whether for stoves or refrigerators, products of the electric enameling furnace are made with a high degree o. uniformity of quality, and with exceptional economy

Transmission Line Insulation and Field Tests Pertaining to Lightning

By W. W. LEWIS

Central Station Engineering Department, General Electric Company

During the past few years more progress than ever before has been made in studying the peculiarities of lightning and in deducing the most effective means to prevent it from interfering with electrical service. A consideration of the results obtained is given in this article which the author presents as a paper this month at the International Conference on Large Electric High-tension Systems, Paris, France.—Editor.

IN the early days of the art, transmission lines were insulated with reference to the normal-frequency voltage. It was soon found however that abnormal voltages were present, caused by lightning, switching, or arcing grounds; and for many years it has been customary to insulate for these abnormal voltages.

Of the several causes of overvoltage, lightning is the only one that gives serious concern at the present time. Lines insulated for lightning will usually withstand safely the abnormal voltages due to switching or to arcing grounds.

As the lightning conditions vary in different localities and at different seasons, naturally the practice in insulating lines varies in accordance with the location of the lines and the experience of the operating engineers.

The information in this article is based almost entirely on experience in the United States, Canada, and Mexico.

In Table I is a list of the standard system voltages, the number of insulator disks used, and their 60-cycle and impulse flashover voltages.

The impulse flashover voltage varies widely, depending upon the nature of the impulse, the steepness of the wave front, the slope and length of its tail, etc. The values given in this article, for the sake of comparison, are based on a particular wave of the following general description: Rises to its crest value in about one-fourth microsecond, then decreases to 50 per cent crest value in about five microseconds (Fig. 1). All flashovers in this treatise take place on the tail of the wave, but crest values of the wave are given in the tables. This will be referred to as the "Pittsfield" wave.

Transformers and other high-tension apparatus have also been supplied with insulation which experience has shown is necessary in order to admit of only a minimum number of failures due to lightning. Such pieces of apparatus are located in stations, protected more or less in various manners, and the insulation of them has not followed the extremes of line insulation, but has rather been based on average conditions.

Apparatus built and insulated in this manner has performed satisfactorily with a few isolated exceptions. The failure of transformers due to all causes, including lightning, has been only a fraction of one per cent per year.

In the past few years there has grown up a demand for a better coördination between line insulation and apparatus insulation, especially transformer insulation, since the transformer is the most vulnerable and usually the most expensive piece of apparatus in the station. It is generally recognized that the potential which can reach the transformer, in the absence of lightning arresters, is limited by the flashover of the line insulators adjacent to the station or the bus insulators in the station. Lightning arresters and the capacitance of the buses to ground, of course, may reduce the potential considerably below the values allowed by the line or bus insulation.

TABLE I

INSULATION OF ACTUAL LINES

System Voltage (Kv.)	Crest Value Line to Neutral Voltage (Kv.)	Number of Insulator Disks		60-cycle Flashover (Kv. r.m.s.)	Impulse Flashover (Kv.)*	Ratio Impulse to Normal Voltage
		Range	Weighted Average			
66	54	4–6	5	305	760	14.1
88	72	5–7	6	355	895	12.4
110	90	6–9	7	405	1030	11.4
132	108	9–12	10	550	1420	13.1
154	126	10–12	10	550	1420	11.3
187	153	10–12	10	550	1420	9.3
220	180	12–18	13	680	1800	10.0

*Based on Pittsfield wave and standard insulators spaced 5¾ in. Insulator strings unshielded.

For the purpose of setting up a uniform criterion, transformer manufacturers have agreed to base the impulse strength of standard transformer designs on the impulse strength of certain insulator strings whose 60-cycle flashover values are given in Table II.

In this table are also given the number of standard disks spaced 4¾ in. and 5¾ in. corresponding to the 60-cycle flashover values given. Also there are given the approximate impulse flashover values of these insulators.

Standard transformers are those receiving a high-potential test of two times normal voltage plus 1000 volts. If the operating engineer wishes to have the impulse strength of the transformers based on a number of insulator disks in excess of the number given in Table II, then the insulation and the 60-cycle high-potential test must be increased accordingly.

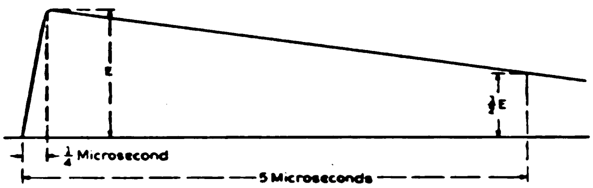


Fig. 1. Representation of Pittsfield Impulse Wave

The principle is also recognized that for impulse voltages the transformer insulation to ground should be stronger than the bushing, *i.e.*, the bushing should flash over and the insulation to ground remain intact.

In order that transformers so designed shall not have undue impulse voltages impressed upon them in service, it is found that the line insulation adjacent to the station or the bus insulation adjacent to the transformers should be limited to an impulse flashover not greater than the values given in Table II. The impulse voltage reaching the transformers should preferably be reduced as much below the values given in Table II as practicable, on account of the turn insulation, the oscillations which may be set up in the interior of the transformer, etc. Such reduction in voltage may be accomplished by means of lightning arresters, spillway gaps, or a combination of arresters and gaps.

In designing the insulation of transmission lines, the following procedure is used: The average height of the conductor is determined and multiplied by an assumed potential gradient. This gradient is taken in the worst case as about 100 kw. per foot of height. The effect of the ground wire or wires is evaluated.(1) The result is the potential for which the insulation must be designed to render the line immune from flashover. For example, assume an average height of conductor of 45 ft. Then the potential at 100 kv. per foot is 4500 kv. Assume that this will be reduced 50 per cent by overhead ground wires. The net potential for which the line must be insulated will then be 2250 kv. Seventeen unshielded disks spaced 5¾ in. have an impulse flashover of about 2300 kv. on the Pittsfield wave. Fifteen disks with Locke grading shields, top and bottom, also have an impulse flashover of about 2300 kv. (an increase in flashover of 12.5 per cent is assumed because of the grading shields.) An insulator string of 15 disks equipped with grading shields is more serviceable than a string of 17 disks without grading shields, because the shields prevent cascading and cause the arc to clear the string so that when flashover occurs no damage is done to the porcelain.

Thus a line of 45 ft. average height, with two ground wires, and with insulator strings of 15 disks equipped with grading rings, will be in theory practically immune from flashover. Experience has shown this to be the case.

SURGE VOLTAGE INVESTIGATION OF TRANSMISSION LINES

In 1926, 1927, and 1928 the General Electric Company conducted a surge voltage investigation in coöperation with various power companies (about 12 in all). The principal instrument used has been the surge voltage recorder (2) (Fig. 2) which was coupled to the transmission line by means of an insulator string potentiometer (Fig. 3). In 1928 a cathode-ray oscillograph (3) (Fig. 4) was installed on the Pennsylvania Power & Light Company's system at Wallenpaupack, and in 1929 it is planned to add other instruments to the equipment.

TABLE II

IMPULSE STRENGTH OF LINE INSULATORS AS CRITERION FOR TRANSFORMER DESIGN

Rated Circuit Voltage (Kv.)	Transformer 60-cycle Test (Kv. r.m.s.)	Line Insulators 60-cycle Dry Flashover (Kv. r.m.s.)	Corresponding Number of Insulator Disks Spaced 4¾ In.	Impulse Flashover (Kv.)*	Corresponding Number of Insulator Disks Spaced 5¾ In.	Impulse Flashover (Kv.)*
66	133	250	5	640	4	620
88	177	350	7	870	6	895
110	221	400	8	980	7	1030
132	265	450	9	1080	8	1160
154	309	550	12	1410	10	1420
187	375	650	15	1730	12	1670
220	441	750	17	1930	14	1930

*Based on Pittsfield wave. Insulator strings unshielded.

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(1) "Relation Between Transmission Line Insulation and Transformer Insulation," by W. W. Lewis. *Trans. A.I.E.E.*, Vol. 47, No. 4, 1928, p. 992.

(2) "Measurement of Surge Voltages on Transmission Lines Due to Lighting," by Lee and Poust. *Trans. A.I.E E.*, Vol. 46, 1927, p. 339.

(3) Cathode Ray Oscillographs and Their Uses," by E. S. Lee, GENERAL ELECTRIC REVIEW, Aug., 1928, p. 404.

A vast amount of data has been collected and analyzed. Some of the more important results will be mentioned in this article.

Nature and Polarity of Surges

Some surge voltages due to lightning are unidirectional and some are oscillatory. Of the unidirectional surge voltages, some are positive and some are negative. Of the oscillatory surge voltages, some have positive characteristics predominating and some have negative.

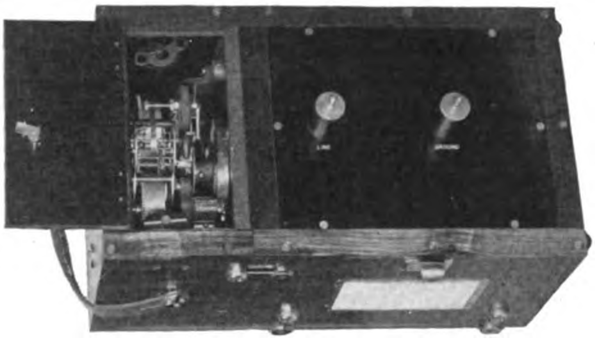

Fig. 2. Surge Voltage Recorder

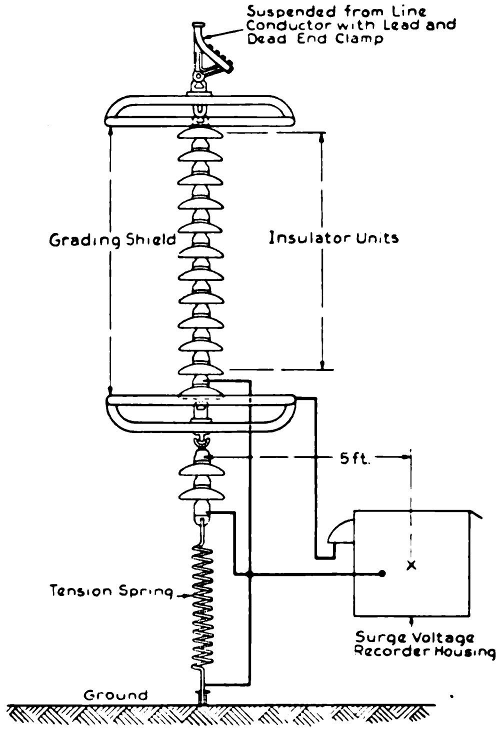
Suspended from Line Conductor with Lead and Dead End Clamp
Grading Shield
Insulator Units
5 ft.
x
Tension Spring
Surge Voltage Recorder Housing
Ground

Fig. 3. Diagram of Insulator String Potentiometer for 132-kv. Line

TABLE III

MAXIMUM VOLTAGE CAUSED BY LIGHTNING, AS MEASURED BY SURGE VOLTAGE RECORDER

System	Rated Voltage (Kv.)	Normal Voltage Crest (Kv. Line-to-Neutral)	Approximate Insulator Flashover Impulse (Kv.)*	MAXIMUM CREST VOLTAGE CAUSED BY LIGHTNING (KV.)			NUMBER OF TIMES NORMAL VOLTAGE		
				1926	1927	1928	1926	1927	1928
Pennsylvania Power & Light Company	220	180	1900	2100+	2100	2700+	11.7	11.7	15.0
Ohio Power Co.	132	114	1300	....	1200	1640	....	11.1	15.2
New England Power Co.	110	108	1000 1400**	240	900	740	2.7	10.0	8.2

*Based on Pittsfield wave. **Insulation increased to 1400 kv. in 1928.

While there may be a trend in some systems toward certain polarity characteristics, the surge voltages recorded are not exclusively of these characteristics. High-voltage surges of negative characteristic are in the majority.

Oscillatory surges have been classified as highly damped (h.d.), medium damped (m.d.), and slightly damped (s.d.).

The h.d. figures* are interpreted as being produced by surge voltages which undergo only a few polarity reversals, say less than five.

The m.d. figures are interpreted as being caused by surge voltages which undergo a moderate number of polarity reversals. Ordinarly, they appear only on systems with isolated neutral, and they are attributed to oscillations following a flashover between line conductor and ground.

The s.d. figures are interpreted as being produced by surge voltages which undergo a large number of polarity reversals. They appear to be formed by a continuous application of a-c. potential for a duration of several seconds, and seem to be connected with a particular potentiometer arrangement. No. s.d. figures

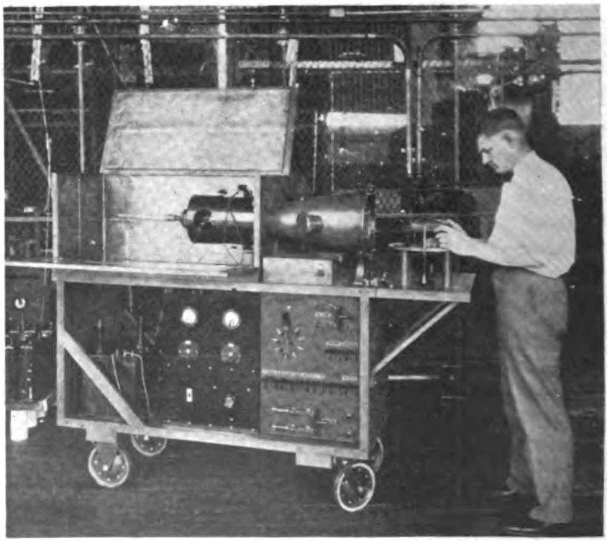

Fig. 4. Cathode-ray Oscillograph

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* The photographic records made by the surge voltage recorder are called "Lichtenberg figures"—Ed.

were produced with the potentiometer arrangement shown in Fig. 3. Examples of the figures produced by various classes of surges are shown in Fig. 5.

Crest Values of Surge Voltages Due to Lightning, Switching, or Arcing Grounds

Lightning. In Table III are listed the maximum voltages due to lightning on three systems for the years 1926, 1927, and 1928, as measured by the surge voltage recorder. (The locations of the surge voltage recorders are indicated in Figs. 6, 7, and 8). The voltages are given both in kilovolts and in the number of times normal crest line-to-neutral voltage. For comparison, also, are given the approximate insulator flashover values as measured by the Pittsfield wave.

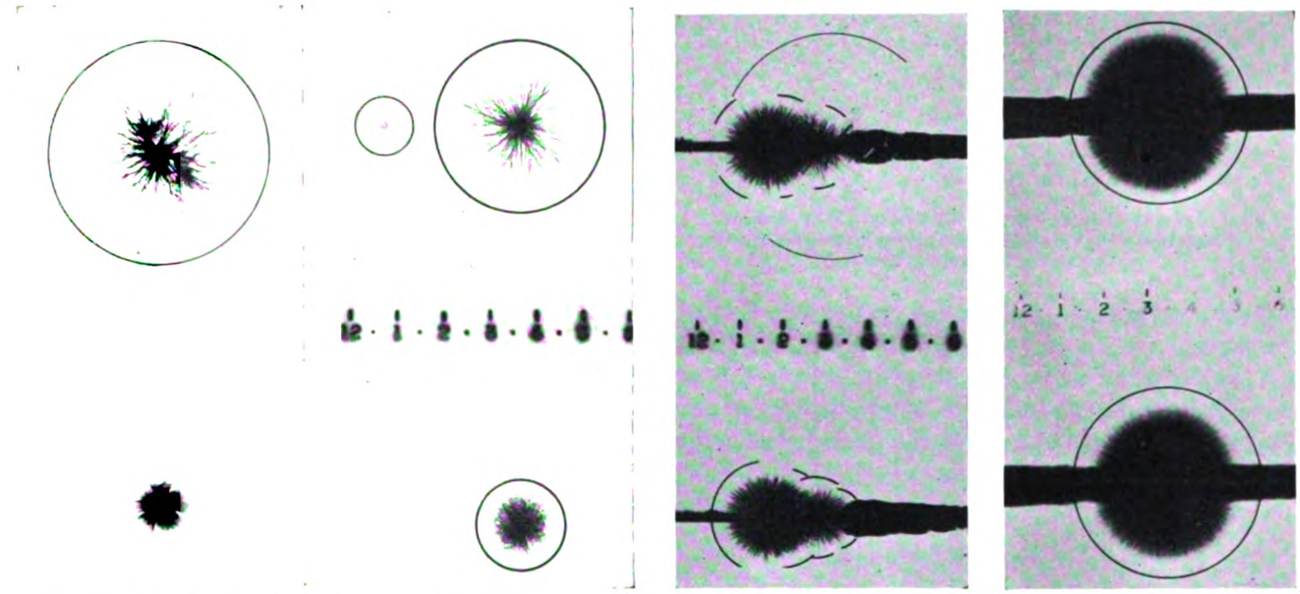


Fig. 5(a). Negative Surge Fig. 5(b). Highly Damped Surge Fig. 5(c). Medium Damped Surge Fig. 5(d). Slightly Damped Surge

Fig. 5. Lichtenberg Figures Illustrating Various Types of Surges

In the case of the Pennsylvania Power & Light Company's line, the conductors are horizontally arranged (Fig. 9) and the insulation consists of 14 disks spaced 5¾ in. with grading rings at the line end only.

TABLE IV

Measured Voltage Caused by Lightning in Kilovolts Per Foot, Based on Average Height of Top Conductor

System	Height of Line at Tower (Feet)	Average Height Top Conductor (Feet)	KV. PER FOOT OF HEIGHT	
			1927	1928
Pennsylvania Power & Light Co.	66	50	42	54
Ohio Power Co.	60 73 86	70	17	23
New England Power Co.	49	40	22	18

The conductors are of 795,000 cir. mils, aluminum, and steel reinforced; and the two overhead ground wires are of 184,000 cir. mils, aluminum, and steel reinforced. The ground wires extend for 20 miles from the Wallenpaupack and 5 miles from the Siegfried end.

On the Ohio Power Company's lines the conductors are vertically arranged (Fig. 10), with 11 insulator disks on top and middle, and 10 disks on bottom conductors, all spaced 4¾ in. The strings are equipped with grading rings at the line end only.

The conductors are of 336,400 cir. mils aluminum, and steel reinforced. Extending the total length of the line there is one overhead ground wire of 159,000 cir. mils aluminum, and steel reinforced.

On the New England Power Company's system there are two circuits with all conductors horizontally arranged (Fig. 11).

The conductors are of 4/0 copper cable (212,000 cir. mils). Previous to 1928 there was one ground wire, and in 1928 a second ground wire was added. The ground wires are of $\frac{7}{16}$-in. steel cable.

Prior to 1928 all conductors were insulated with 8 disks spaced 5 in. with no grading rings. In 1928 the insulation was increased to 10 disks on the two outside conductors and to 9 on the conductors adjacent to the two outside ones, while 8 disks were retained on the two innermost conductors. Grading rings were added to all strings at both line and ground ends.

In Table IV are given the height of line at tower and the average height of top conductor, also the kilovolts per foot of height, as measured by surge voltage recorders in 1927 and 1928.

In Fig. 12 are plotted the surge voltages caused by lightning during the year 1927. The abscissas represent times normal crest line-to-neutral voltage, and the ordinates represent percentages of the total

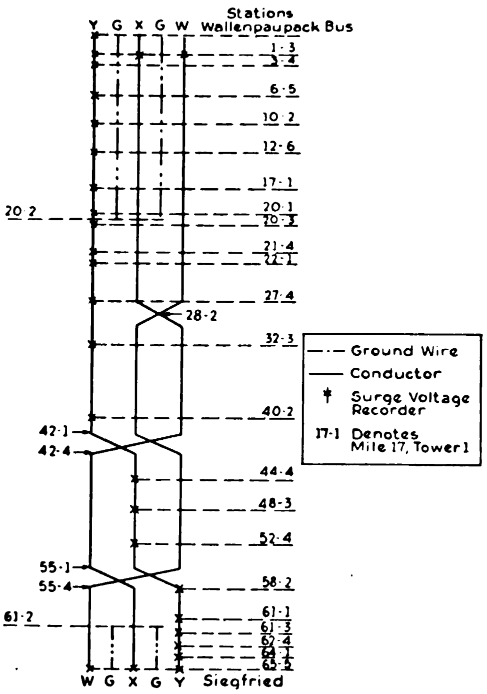

Stations
Y G X G W Wallenpaupack Bus
1·3
3·4
6·5
10·2
12·6
17·1
20·2
20·1
20·3
21·4
22·1
27·4
28·2
32·3
40·2
42·1
42·4
44·4
48·3
52·4
55·1
55·4
58·2
61·2
61·1
61·3
62·4
64·1
65·2
W G X G Y Siegfried
Ground Wire
Conductor
Surge Voltage Recorder
17·1 Denotes Mile 17, Tower 1

Fig. 6. Location of Surge Voltage Recorders on 220-kv. System o Pennsylvania Power and Light Co. From Wallenpaupack to Siegfried is a distance of 65 miles

number exceeding the value indicated by the abscissas.

A similar set of curves is plotted for 1928 in Fig. 13. In 1928 the maximums were somewhat higher than for previous years. In general the majority of surges are less than five times normal.

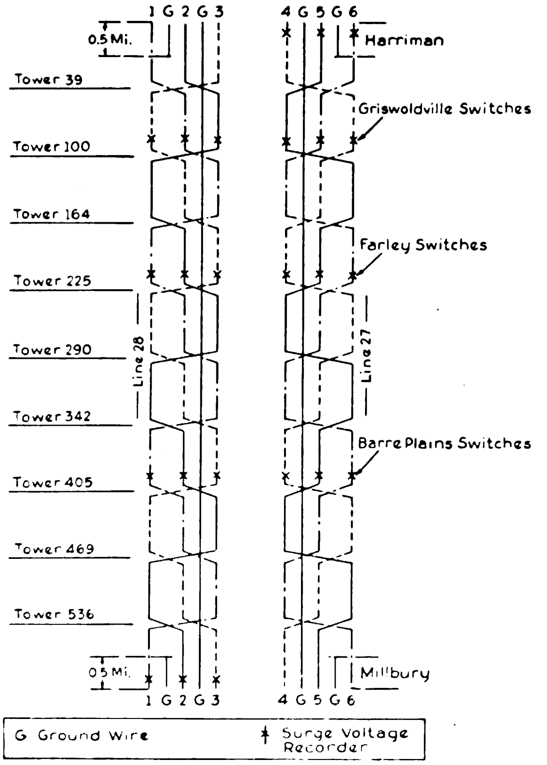

1 G 2 G 3
4 G 5 G 6
0.5 Mi.
Harriman
Tower 39
Griswoldville Switches
Tower 100
Tower 164
Farley Switches
Tower 225
Tower 290
Line 28
Line 27
Tower 342
Barre Plains Switches
Tower 405
Tower 469
Tower 536
0.5 Mi.
Millbury
1 G 2 G 3
4 G 5 G 6
G Ground Wire
Surge Voltage Recorder

Fig. 8. Location of Surge Voltage Recorders on 110-kv. System of the New England Power Co. From Harriman to Millbury is a distance of 74 miles

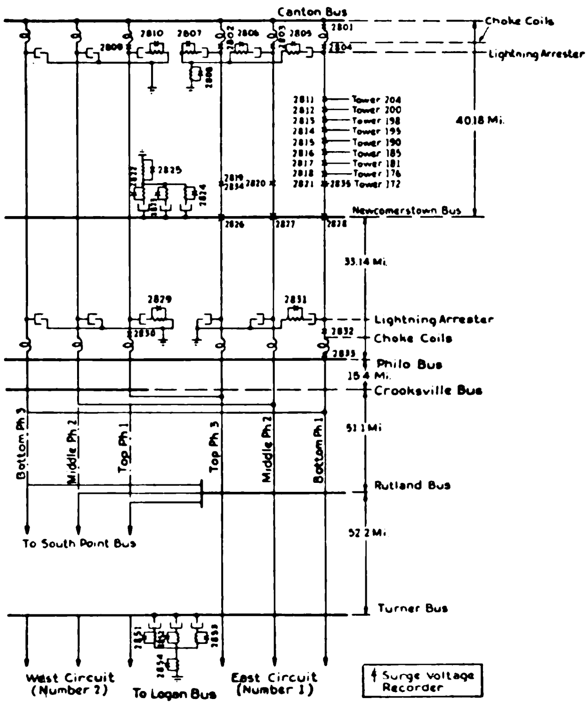

Canton Bus
Choke Coils
Lightning Arrester
2810
2807
2806
2805
2801
2804
2809
2808
2802
2803
2811
2812
2813
2814
2815
2816
2817
2818
2821
2835
Tower 204
Tower 200
Tower 198
Tower 195
Tower 190
Tower 185
Tower 181
Tower 176
Tower 172
40.18 Mi.
2825
2822
2823
2824
2819
2834
2820
Newcomerstown Bus
2826
2827
2828
33.14 Mi.
2829
2831
2830
Lightning Arrester
2832
Choke Coils
2833
Philo Bus
15.4 Mi.
Crooksville Bus
Bottom Ph.3
Middle Ph.2
Top Ph.1
Top Ph.3
Middle Ph.2
Bottom Ph.1
51.1 Mi.
Rutland Bus
To South Point Bus
52.2 Mi.
Turner Bus
West Circuit (Number 2)
To Logan Bus
East Circuit (Number 1)
Surge Voltage Recorder

Fig. 7. Location of Surge Voltage Recorders on 132-kv. System of Ohio Power Co. From Canton to Turner is a distance of 192 miles

Switching

Table V gives the maximum voltage caused by switching, as measured during the years 1926, 1927, and 1928.

In Fig. 14 are plotted the curves for switching surges for the year 1927, the abscissas representing number of times normal crest line-to-neutral voltage and the ordinates representing percentage of all surges exceeding the given number of times normal given on the abscissas. In Fig. 15 are plotted similar data for 1928.

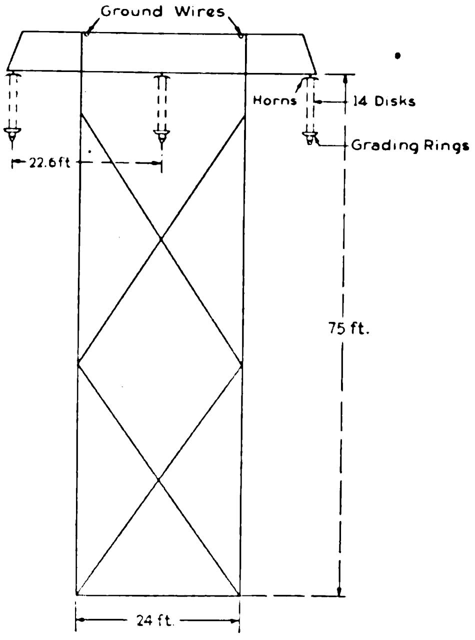

Ground Wires
Horns
14 Disks
Grading Rings
22.6 ft
75 ft.
24 ft.

Fig. 9. Arrangement of Conductors on Pennsylvania Power & Light Company's System

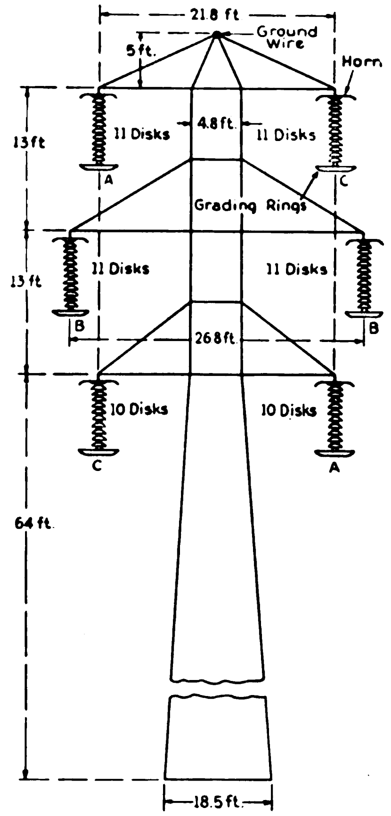

21.8 ft
Ground Wire
5 ft.
Horn
13 ft
11 Disks
4.8 ft.
11 Disks
A
C
Grading Rings
13 ft
11 Disks
11 Disks
B
B
26.8 ft.
10 Disks
10 Disks
C
A
64 ft.
18.5 ft.

Fig. 10. Arrangement of Conductors on Ohio Power Company's System

The majority of all switching surges are less than three times normal.

In general it was noted that deënergizing was slightly more severe than energizing. Switching load on and off gave a very mild overvoltage disturbance (of the magnitude of 1.2 times normal on the Ohio Power Company's system).

Arcing Grounds

It is not possible from this investigation to separate lightning surges from the arcing ground or switching surges which follow in many cases. The initial surge caused by lightning and the subsequent surges due to arcing grounds or switching are shown as one surge by the recorder.

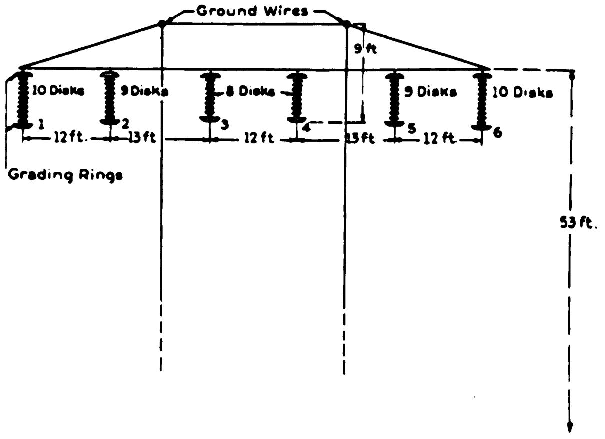

Ground Wires
9 ft
10 Disks
9 Disks
8 Disks
9 Disks
10 Disks
1
2
3
4
5
6
12 ft.
13 ft
12 ft
13 ft
12 ft.
Grading Rings
53 ft.

Fig. 11. Arrangement of Conductors on the New England Power Company's System

The Consumers Power Company is the only one of the systems in this investigation operating with an isolated neutral, and therefore the only one subject to overvoltage by reason of arcing grounds. It is

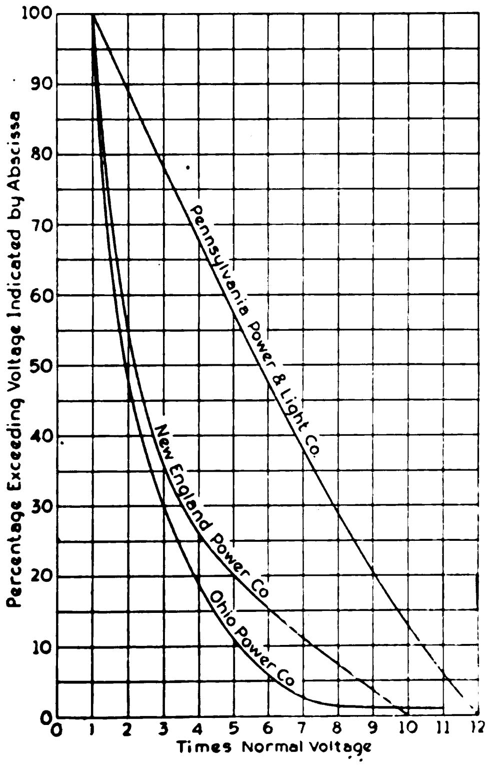


Fig. 12. Values of Surge Voltages Caused by Lightning, 1927

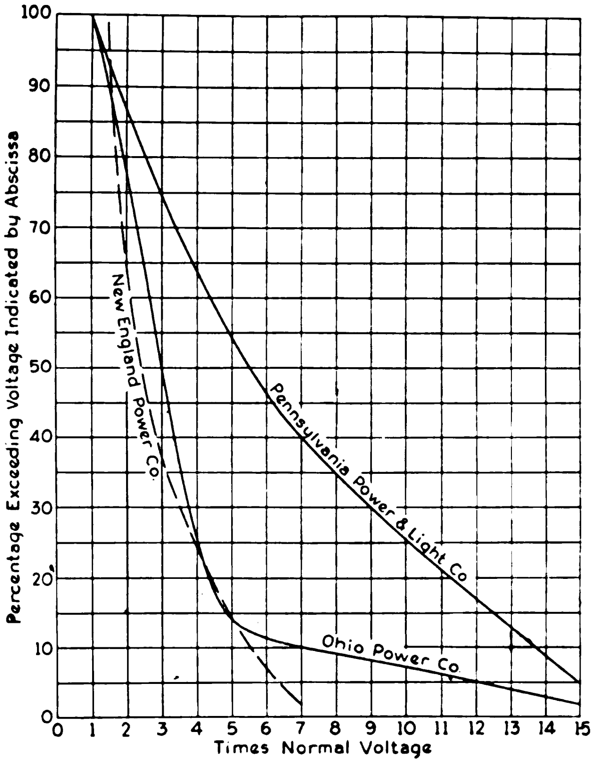
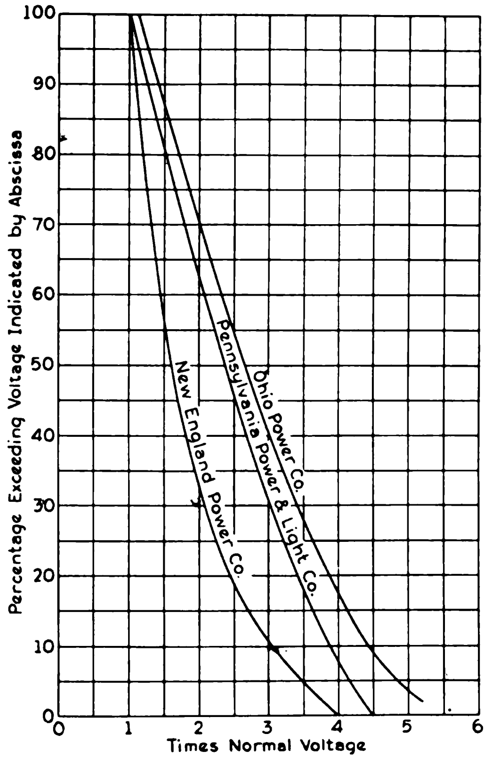


Fig. 13. Values of Surge Voltages Caused by Lightning, 1928

possible that the m.d. figures found only on this sytem were caused by arcing grounds. Pure m.d. figures were found of a magnitude of 7.7 times normal. Theoretically, the maximum voltage that can be obtained from arcing grounds is about six times normal.(4)

General

From the data given it may be concluded that a transmission line insulated for about six times normal voltage will be fairly safe from flashover due to switching or arcing grounds. The average system is insulated for this voltage or better.(4) The average system is also insulated for impulse voltages of 9 to 14 times normal (Table I), which apparentiy is not quite high enough to prevent flashover under the worst conditions (Table III).



ig. 14. Values of Surge Voltages Caused by Switching, 1927

Tripouts Caused by Lightning, and Flashed Insulator Strings

The number of surges caused by lightning, as measured by the surge voltage recorder, is given in Table VI for the years 1926, 1927, 1928 on three systems, also the number of line tripouts. The data on the number of surges is given for the portion of the year indicated in the last column of the table, while the data for the tripouts covers the whole year. It is evident that there are many more surges recorded than there are tripouts.

Data compiled on these systems also show that there are as a rule from one to five insulator strings or assemblies flashed over for each tripout. In other words, each stroke which causes a flashover usually affects more than one string or assembly, either on the same tower or on adjacent towers.

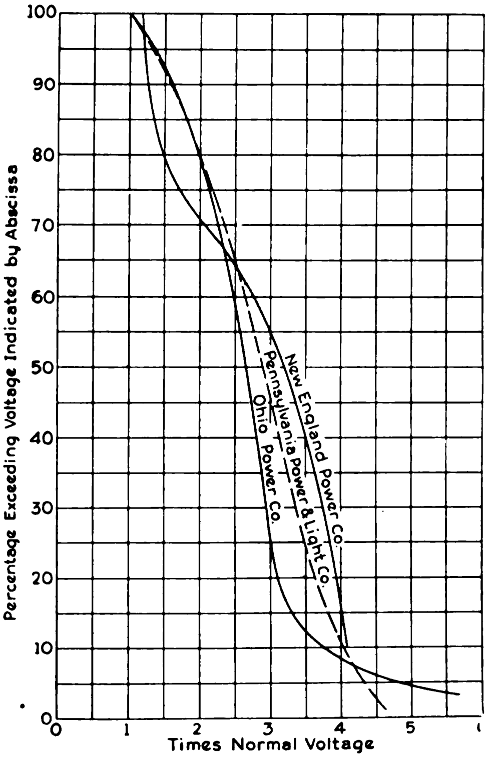


Fig. 15. Values of Surge Voltages Caused by Switching, 1928

Statistics also indicate that where there are two circuits on a tower from 5 to 25 per cent of the strokes affect insulator strings on both circuits.

In case of circuits with conductors horizontally arranged, or two circuits with some horizontal distance between them, statistics indicate that the conductor or circuit on the side from which the storms generally approach suffer the greatest number of

TABLE V

MAXIMUM VOLTAGE CAUSED BY SWITCHING, AS MEASURED BY SURGE VOLTAGE RECORDER

System	Rated Voltage (Kv.)	Normal Voltage Crest (Kv. Line-to-Neutral)	MAXIMUM CREST VOLTAGE DUE TO SWITCHING			NUMBER OF TIMES NORMAL VOLTAGE		
			1926	1927	1928	1927	1927	1928
Pennsylvania Power & Light Co.	220	180	630	720	845	3.5	4.0	4.7
Ohio Power Co.	132	114	....	560	595	...	5.2	5.5
New England Power Co.	110	108	207	360	370	2.3	4.0	4.1

---

(4) "Transmission Line Engineering," by W. W. Lewis, McGraw-Hill Book Co., Chapter VII.

insulators damaged. For example, on the Pennsylvania Power & Light Company's 220-kv. line from Wallenpaupack to Siegfried, during the three years 1926, 1927, and 1928, there were 40 insulator strings flashed over on the west or storm wire, 17 on the middle, and 23 on the east wire.

On the Hartford Electric Light Company's system, a 66-kv. line 33 miles long, with two circuits vertically arranged on the same towers, runs generally northwest. The southwest circuit is on the windward side and the side toward approaching thunder storms. Three years' operation of this line showed that trouble from insulator flashover and failure was more than twice as great on the southwest circuit as on the other or lee circuit.

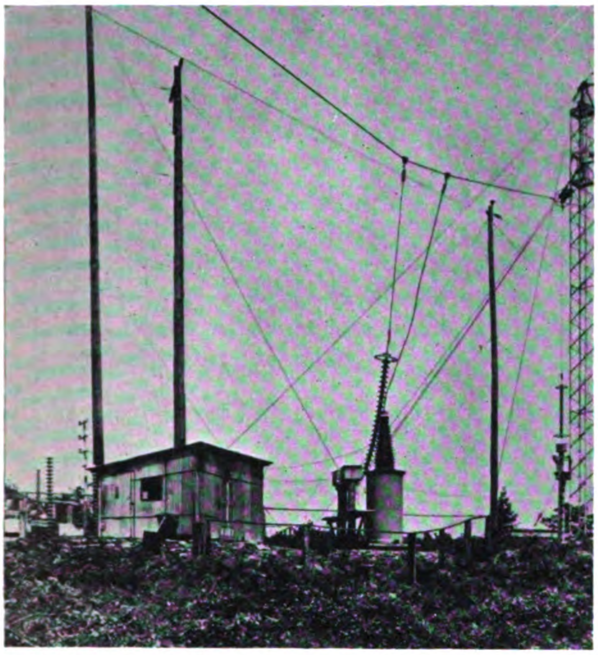


Fig. 16. View of Lightning Laboratory at Wallenpaupack on the Pennsylvania Power & Light Co's. System. Note surge voltage recorders and coupling potentiometers

Wave Front and Wave Shape

An analysis of 150 figures obtained by surge voltage recorder in 1927 on three different systems gave the following rough summary as to the duration of the wave front of the surges producing the figures: One surge less than 1 microsecond; about 20 per cent of all surges between 1 and 10 microseconds; about 20 per cent between 10 and 100; and about 60 per cent over 100 microseconds.

In 1928 additional information on wave front and duration of waves was obtained by special connections of the surge voltage recorders on the Pennsylvania system. The results indicated surges with fronts from 0.1 to 25 microseconds and a duration of the first loop from 0.25 to 50 microseconds.

A cathode-ray oscillograph was installed in the lightning laboratory (Fig. 16) on the Pennsylvania system at Wallenpaupack (Tower 1-3) during the latter part of the 1928 season, and one oscillogram was obtained of a lightning surge. The following brief description of the surge should be of interest:

During a lightning storm which crossed the transmission line several miles south of the laboratory on July 27th, lightning struck, or struck near, the line. The transmission line breakers tripped at both Wallenpaupack and Siegfried. Arc-overs occurred on the middle and east phases of the line at a tower approximately 16½ miles south of the laboratory (Fig. 17). Three insulators were broken on the middle phase and many of the units on the east phase were flashed. At the same time observers at Tower 1-3, the oscillograph location, heard a surge and other observers standing near a tower 300 ft. closer to the power plant saw the middle phase flash-over. At this tower the spacing between shielding rings is reduced to form an electrical spillway for the protection of terminal apparatus. The cathode-ray oscillogram obtained on the west phase at Tower 1-3 is shown in Fig. 18. The surge was positive in polarity, rose to maximum in 8 microseconds, reduced to 50 per cent of that value in 17 microseconds and to zero in 35 microseconds. The crest voltage of the main wave was approximately 600 kv.

Superimposed upon the fundamental surge is a 2,000,000-cycle highly-damped oscillation. This occurred at the peak of the surge and was probably

TABLE VI

NUMBER OF SURGES AND NUMBER OF TRIPOUTS CAUSED BY LIGHTNING

System	Rated Voltage (Kv.)	NUMBER OF SURGES CAUSED BY LIGHTNING MEASURED BY SURGE VOLTAGE RECORDER			NUMBER OF LINE TRIPOUTS CAUSED BY LIGHTNING			Period During which Surge Voltages Were Measured
		1926	1927	1928	1926	1927	1928	
Pennsylvania Power & Light Co......	220	33	48	28	16	7*	14	1926 July 20—Oct. 24 1927 March 12—Nov. 2 1928 April 15—Oct. 1
Ohio Power Co......................	132	..	166	46	15	4	12	1927 May 11—Oct. 16 1928 April 29—Oct. 20
New England Power Co.............	110	14	104	47	11	43	5	1926 July 28—Sept. 12 1927 June 6—Oct. 10 1928 June 23—Oct 8

NOTE: Tripouts are given for the whole year.

*Line out of service two months during lightning season, installing ground wires.

induced by the flashover of the adjacent phase at the peak of the wave. A surge voltage recorder connected to the line on the same conductor 17 miles south of the laboratory registered a potential of 2100 kv. Other recorders distributed along the line showed how this voltage decreased as it traveled (Fig. 19).

A recorder located approximately 90 ft. north of the cathode-ray oscillograph on the same phase (west) indicated 1000 kv., and another recorder at the same location but on the east phase indicated about 1700 kv.

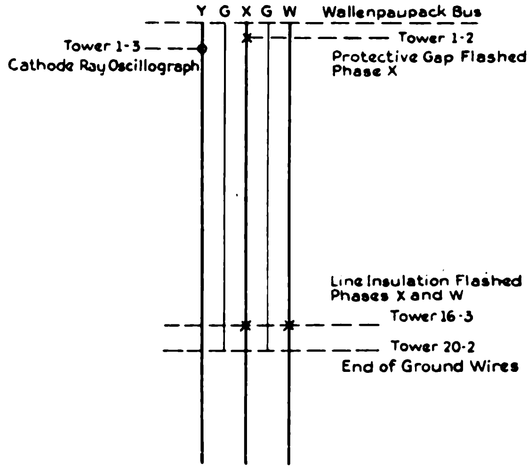


Fig. 17. Location of Cathode-ray Oscillograph and Evidences of Lightning Surge on Pennsylvania System, July 27, 1928

K. B. McEachron of Pittsfield has been experimenting with a 66-kv. line insulated for 110 kv. This line consists of two circuits on the same towers, vertically arranged, with an overhead ground wire. The line is the property of the Turners Falls Power Co. and terminates at Pittsfield.

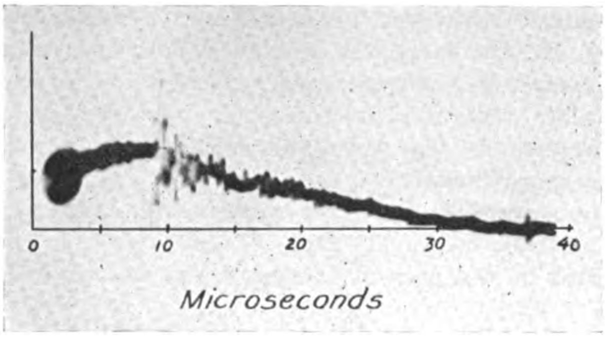


Fig. 18. Cathode-ray Oscillogram of Surge on Pennsylvania System, July 27, 1928

A portable impulse generator is moved to different points on the line and impulses are sent on to the line. Cathode-ray oscillograms of these impulses are recorded at Pittsfield. By these tests it is hoped to learn a great deal about effect of wave shape on attenuation, effect of overhead ground wire, effect of lightning arresters, effect of choke coils, etc. A preliminary report on this investigation has been published.(5)

Attenuation

In 1927 plots (Fig. 20) were made of a number of surges which appeared at more than one station on the systems of the Pennsylvania Power & Light Co. and the New England Power Co. with distance from an assumed origin as abscissas and voltage as ordinates. An average curve was drawn(6) and equations determined for the variation of voltage with distance, and the rate of change of voltage with distance, or attenuation. These equations are as follows:

$$e = \frac{e_0}{kse_0 + 1} \qquad (1)$$

$$A = -ke^2 \qquad (2)$$

in which

e_0 = initial surge voltage at the point where the surge originated.

k = a proportionality factor which is found empirically.

s = distance in miles from the origin of the surge.

e = voltage at any distance (s).

A = the attenuation in kilovolts per mile.

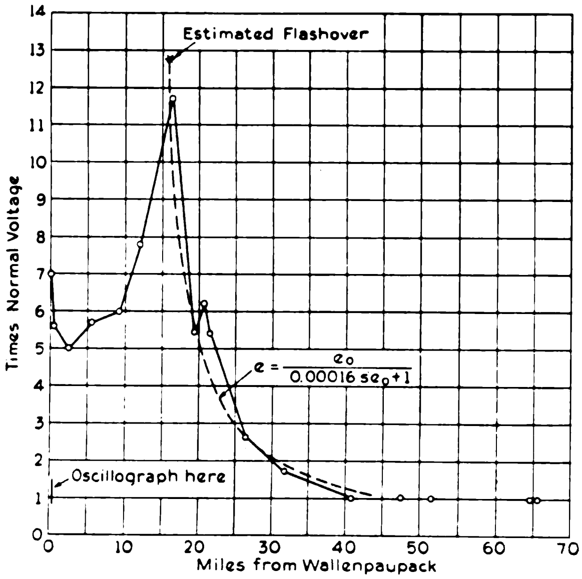


Fig. 19. Attenuation of Surge which Took Place July 27, 1928, on Pennsylvania System

(See Fig. 18 for oscillogram of surge.)

The factor k for the surges investigated was found to be 0.00016.

These equations are used as in the following examples:

Example 1

Assume the initial potential to be 2000 kv. Then at a distance 10 miles from the origin

$$e = \frac{2000}{(0.00016 \times 10 \times 2000) + 1} = 477 \text{ kv.}$$

---

(5) "Cathode-ray Oscillograph Study of Artificial Lightning Surges on the Turners Falls Transmission Line," by K. B. McEachron and V. E. Goodwin, Cincinnati Meeting of A.I.E.E., March, 1929.

(6) "Symposium on Surge Voltage Investigation," by W. W. Lewis, E. W. Dillard, J. G. Hemstreet, J. R. Eaton, P. Sporn, and N. N. Smeloff, *Trans. A.I.E.E.*, Vol. 47, No. 4, 1928, p. 1111.

The attenuation at the point of origin of the surge is

$$\begin{aligned} A &= -0.00016 \times 2000^2 \\ &= -640 \text{ kv. per mile} \end{aligned}$$

Example 2

If the initial surge were only 1000 kv. in magnitude, the attenuation would be

$$\begin{aligned} A &= -0.00016 \times 1000^2 \\ &= -160 \text{ kv. per mile.} \end{aligned}$$

As a limiting case for any line, the flashover value of the line insulation may be taken as the initial voltage.

Equations (1) and (2) state that the voltage varies inversely as the distance and that the attenuation varies as the square of the voltage. Since attenuation depends on the resistance loss in the conductor and the corona loss, and since it is known that resistance loss accounts for only a small amount of attenuation, the greater part of it must be due to corona loss. Corona loss varies as the square of the voltage, so that the attenuation Equation (2) seems to tie in with the corona loss.

Equations (1) and (2) are plotted in curve form in Fig. 21, assuming initial voltage (e_0) equals 1000 kv. In this illustration, attenuation has been plotted for convenience as positive, although it will be noted from Equation (2) that it is a negative function.

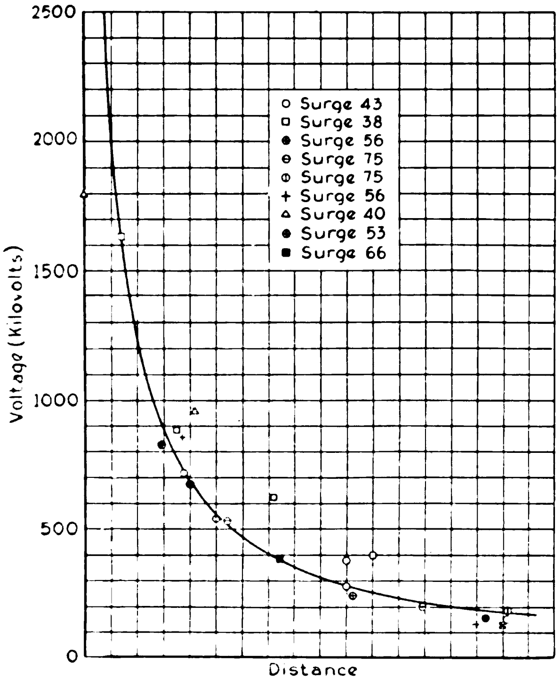


Fig. 20. Curve Showing Variation of Voltage with Distance for Various Surges. Surges 38 and 40 were on Pennsylvania Power & Light Company's System. All others on New England Power Company's system. All surges occurred in 1927

In 1928 a further study of the subject was made. Two surges on the New England Power Company's system lent themselves to analysis, and from these surges factors of 0.00013 and 0.0002 were obtained.

On the Pennsylvania Power & Light Company's system an analysis of two surges gave factors of 0.00013 and 0.00016.

On the Ohio Power Company's system three surges gave factors of 0.0005, 0.0006 and 0.0007. This system has a smaller conductor than the other two, also a ground wire closer to the conductors. Both of these features would call for a greater corona loss and consequently a faster attenuation than on the New England or Pennsylvania systems. Hence, the larger factor k found for the surges examined appears reasonable.

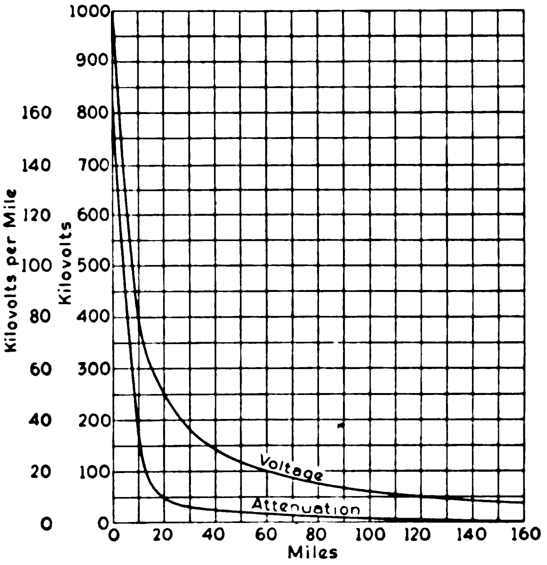


Fig. 21. Variation of Voltage with Distance and Rate of Decrease of Voltage with Distance from Equations (1) and (2). Initial voltage 1000 kv.

A number of surges have been recorded which registered on instruments at only 1, 2, or 3 stations. The attenuation of these surges was sometimes much faster than indicated by the factors (k) previously discussed.

It is possible that, in addition to the conductor size and proximity of ground wires, the shape of the wave, its front, and duration may affect the attenuation, consequently the factor k.

Effect of Overhead Ground Wires in Reducing Surge Voltages

Ohio Power Company's System

In 1927 approximately 50 surges were measured simultaneously on top, middle, and bottom conductors of the vertically arranged circuits; and in 1928 five surges were recorded. This line is a double-circuit line with one overhead ground wire above and midway between the two circuits.

In Table VII is given the theoretical potential of the three conductors without ground wire, expressed in per cent, on the assumption that the bottom conductor is 100 per cent and that the other conductors have potentials proportionate to their heights above ground. Then there is given the theoretical potential with ground wire, still assuming that the bottom conductor is 100 per cent and using the protective ratios given in footnote reference⁽¹⁾, *i.e.*, 0.42, 0.52, and 0.62 for top, middle, and bottom conductors, respectively. Finally, there are given the averages of the surge voltage recorder readings expressed in per cent, with the bottom conductor as 100 per cent.

In the case of the top conductor, two values are given under the column of measured potential: The first is a comparison of the surges on the top and middle conductors, and the second of the surges on the top and bottom conductors. The results are illustrated graphically in Fig. 22.

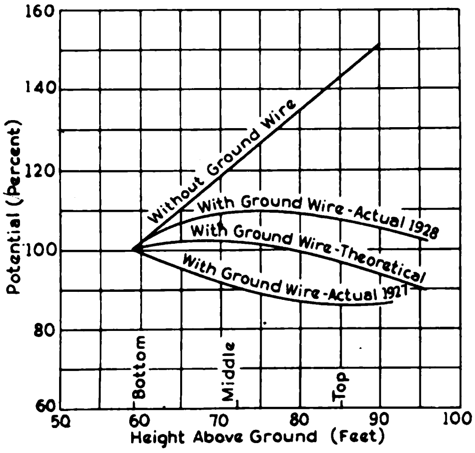


Fig. 22. Curves Illustrating Ground-wire Protection, Ohio Power Company's System, 1927 and 1928

New England Power Company's System

This transmission line consists of two circuits horizontally arranged. The conductors may be designated 1, 2, 3, 4, 5, 6. In 1927 there was one ground wire above and between conductors 2 and 3. Instruments were installed on all six conductors at two places, Griswoldville and Barre. The readings on these instruments did not necessarily indicate the potential due to the conductor position at that point, because the conductors were frequently transposed. The fairest attempt to evaluate the effect of the ground wire was to select those surges which had their highest values at one of the stations and which therefore presumably originated near that station. For this purpose five surges which had their highest values at Barre were studied. The average values of the surges expressed in times normal are given in Table VIII.

In 1928 a second ground wire was placed above and between Conductors 4 and 5. The average values of two surges having their highest values at Barre are given in Table VIII.

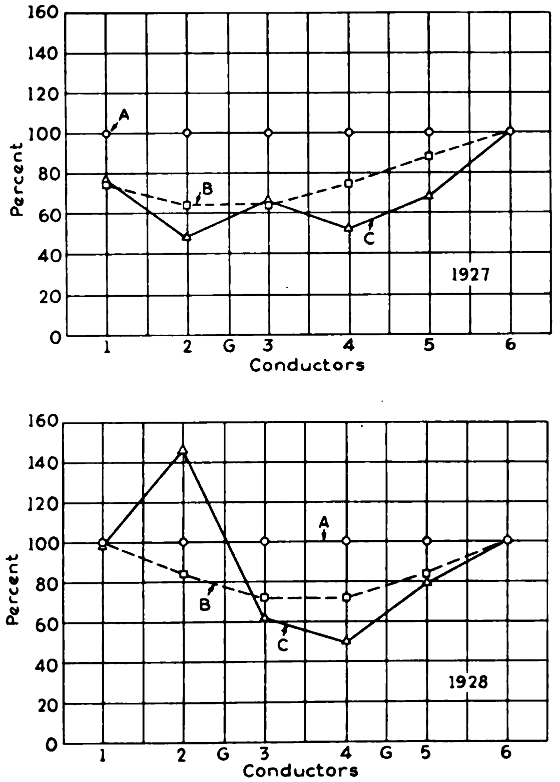


Fig. 23. Curves Illustrating Ground-wire Protection. New England Power Company's System, 1927 and 1928

A: Without ground wires.
B: With ground wires (estimated).
C: With ground wires (measured by surge voltage recorder).

The number of insulator flashovers, storms, and tripouts for 1927 and 1928 are also given. The results in 1928 indicate a more even distribution of the potentials on the various conductors, with the outside conductors registering the highest voltages. Although the number of storms was practically the same in the two years, the number of tripouts in 1928 was decidedly less than in 1927. The results are illustrated graphically in Figs. 23 and 24.

TABLE VII
EFFECT OF OVERHEAD GROUND WIRE
OHIO POWER COMPANY

Conductor	Approximate Height at Tower (Feet)	Theoretical Potential without Ground Wire (Per cent)	Theoretical Potential with Ground Wire* (Per cent)	MEASURED POTENTIAL WITH GROUND WIRE AVERAGE OF READINGS (PER CENT)	
				1927	1928
Top	85	143	97	83–89**	99–116**
Middle	72	121	102	91	110
Bottom	59	100	100	100	100

*Calculated by means of tables in footnote reference (1).
**First figure is comparison of top to middle, and second figure comparison top to bottom conductor.
1927 figures average of 51 to 54 surges.
1928 figures averages of 5 surges.

In this connection it must be remembered that, in addition to adding the second ground wire in 1928, the line insulation was also considerably improved, being increased from 8 disks on all conductors to 10, 9, 8, 8, 9, 10 disks. Grading rings were also added at both line and ground ends of all strings. Taken altogether, a remarkable increase in continuity of service was shown by the 1928 performance.

A similar improvement was shown on the Ohio Power Company's system previously considered. In 1925 there were 88 tripouts. In 1926 a ground wire was added and grading rings at the line end of all strings. The tripouts, as shown by Table VI, have not exceeded 15 per year since that time. There is no doubt that the ground wire should be credited with some of this improvement in operation.

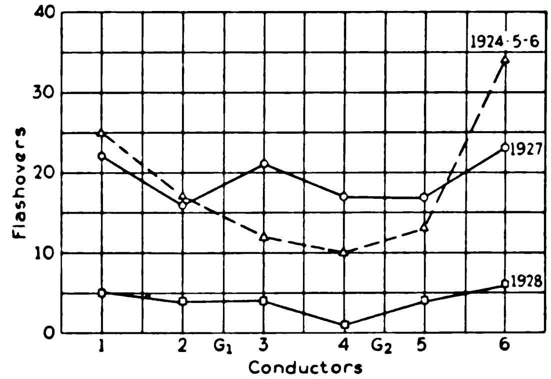


Fig. 24. Curves Showing Insulator Flashover on New England Power Company's System, 1924 to 1928. Ground wire G_2 was installed in 1928

The Overhead Systems Committee of the Great Lakes Division, National Electric Light Association(7) made a study of the operation of high-voltage transmission lines during 1927. The lines without overhead ground wire (728 miles) had 12.2 interruptions per 100 miles, caused by lightning, while the lines with overhead ground wires (1511 miles) had 5.9 interruptions per 100 miles, caused by lightning.

The Texas Power & Light Co. in 1925 had 726 miles of 60-kv. line with overhead ground wire and 491 miles without overhead ground wire. The interruptions were 28 and 75 respectively. In 1926 the company had 800 miles with overhead ground wire and 784 miles without overhead ground wire, and the interruptions were 64 and 220 respectively.

All these data, though incomplete, give corroborative evidence of the value of the overhead ground wire in improving the continuity of service.

Conclusions

Surge voltages of the following upper magnitudes have been measured on power systems:

Caused by lightning—15 times normal
Caused by switching—5.5 times normal

It has been established that the voltage is limited by the flashover strength of the line insulators, which varies through wide values depending upon the shape and duration of the wave. For average systems, with the Pittsfield wave, the insulator flashover is 9 to 14 times normal voltage (normal voltage equals crest value of line-to-neutral voltage).

Very little is known about the shapes of waves encountered in lightning and other line disturbances. One wave measured with the cathode-ray oscillograph rose to its crest in 8 microseconds and had a total duration of 35 microseconds. The wave front varies through wide limits. Of 154 surges examined, about one-fifth had fronts between 1 and 10 microseconds, about one-fifth between 10 and 100 microseconds and about three-fifths over 100 microseconds.

An empirical formula has been derived from attenuation. This is of the form $A = -ke^2$; *i.e*, the attenuation is faster the higher the voltage. The form of this equation is similar to that for corona loss, $P = ce^2$, and indicates that the attenuation is due mainly to corona

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(7) Report of Overhead Systems Committee, Great Lakes Division, National Electric Light Association, Sept., 1928.

TABLE VIII

EFFECT OF OVERHEAD GROUND WIRE

NEW ENGLAND POWER COMPANY

Surge Voltages Having Their Highest Voltage at Barre

	1927						1928					
		G						G		G		
Conductor position	1	2	3	4	5	6	1	2	3	4	5	6
Average of surge voltages (number of times normal)	4.8	3.1	4.2	3.3	4.4	6.4	4.2	6.4	2.7	2.1	3.4	4.3
Surge voltages in per cent (assuming Conductor 6 as 100%)	75	49	66	52	69	100	98	146	63	49	79	100
Theoretical protective ratio* in per cent	74	64	64	74	89	100	100	84	72	72	84	100
Insulator flashovers	22	16	21	17	17	23	5	4	4	1	4	6
Lightning storms	22						20					
Insulator flashovers	116						24					
Tripouts	43						5					

*From footnote reference (1). G = ground wire.

loss. The factor *k* was found to be about 0.00016 on two systems and varied from 0.0005 to 0.0007 on a third system (distance being expressed in miles).

The value of the overhead ground wire in reducing overvoltage and improving continuity of service is clearly indicated by experience.

Future work should follow along the line of obtaining more exact data as to the shape of the waves that lightning surges cause on transmission lines, with parallel studies showing how such waves are affected by the line characteristics and by apparatus. The cathode-ray oscillograph will play a large part in this work.

On the Pennsylvania Power & Light Company's system, short antenna (about 300 ft. long) have been erected at a number of places at various heights above the ground. These are connected to ground through high resistance and are equipped with surge voltage recorders. It is hoped to learn from these the actual voltages built up in space by overhead clouds.

The importance of continuity of service warrants the spending of considerable time and money to obtain the fundamental data applying to the problem of lightning and the protection from its effects.

Resonant-circuit Frequency Meter Sets New Standard of Accuracy

The requirement for a more accurate frequency meter for central station work has brought forward the production of a new group of resonant-circuit-type instruments in which the full-scale range may be as small as a single cycle. These meters are of horizontal edgewise design, long found to be most satisfactory for this class of device.

The most sensitive meter of this new group has a full-scale range between 59.5 and 60.5 cycles. Other ranges, of 2, 5, and 10 cycles full scale, are provided for service on 25, 50, and 60-cycle systems. All are intended for 110-volt operation.

In the design of these meters accuracy has been held of main importance. Even when operated under extreme conditions, there are no appreciable voltage, wave-form or temperature errors. The resonant-circuit principle gives a deflecting torque which is proportional to the difference in the squares of the currents in two resonant circuits, thus making possible large deflections for very small changes in frequency. A further contribution to accuracy is secured in the horizontal edgewise arrangement by virtue of both the low friction of the vertical bearing construction and the fact that extremely close readings may be made because of the juxtaposition of the needle and scale.

What Electricity Costs the Average Family

About $2.40 a month, or $28.30 a year, is the amount spent by the average American family for enough electricity to comfortably light the home and operate several labor-saving electrical devices such as the iron, vacuum cleaner, toaster, and fan, according to statistics gathered by the National Electric Light Association.

Of the nearly eighty billion kilowatt-hours of electricity generated in the United States in 1927, about ten billion were used for lighting and operating electrical appliances in 18,000,000 homes; twenty billion for industrial lighting in shops, stores, and offices; approximately forty billion for power purposes, part of which was also used for lighting in places where power was used; and ten billion for traction and miscellaneous uses.

The total gross revenue received by power companies for all electric current in 1927 was less than two billion dollars, or an average of about two and one-half cents per kilowatt hour.

The Electrification of the Mexican Railway

PART I

By J. B. COX
Railway Engineering Department, General Electric Company

THE electrification of the Mexican Railway (Ferrocarril Mexicano) is of special interest as being the first undertaking of this nature carried out in old Mexico. The author of the present article made the initial study of the problems involved in 1921 and a contract was signed for the construction work and for the electrical equipment in 1922. The work was completed and electrical operation started in 1925.

The operation has been so conspicuously successful that it would now seem to be of general interest to describe many of the details of construction and to give such operating data as are available.

The main line of the Mexican Railway extends from Mexico City to the Gulf Coast at Vera Cruz; it is 264 miles in length, and there are six branch lines. Details are given in Table I:

TABLE I

STANDARD GAUGE (4 ft. 8½ in.)	Miles
Vera Cruz to Mexico	264
Apizaco to Puebla	29
Ometusco to Pachuca	29
Pachuca to Ixmiquilpan	51
	373
Sidings and Second Track	74
	447
NARROW GAUGE	
Huajuapam Branch (3 ft.)	56
Zacatlan Branch (2 ft. 6 in.)	30
Huatusco Branch (2 ft.)	20
	109
Total Mileage	556

From Mexico to Esperanza the line follows the general contour of the plateau, resulting in frequent reversal of gradients, but none exceeding 1.5 per cent. The elevation at the terminus in Mexico City is 7346 ft. The highest point on the line is near Acocotla, 95 miles from Mexico, with an elevation of 8320 ft., making a rise of about 1000 ft. From this point to Esperanza, a distance of 58 miles, the drop is 240 ft. with the surface undulating as before.

At Boca del Monte (the Mouth of the Mountain), 3.8 miles east of Esperanza, the plateau ends suddenly and the descent for the following 19.0 miles to Encinar is very rapid. At Santa Rosa the line enters the Valley of the Rio Blanca and the grade becomes normal on to Orizaba.

From Orizaba to Paso del Macho the drop is considerable, though much less rapid than that just described. In the 35 miles there is a descent of 2466 ft. There are some comparatively long sections of tangent track, and the curves, except in the Baranca, are not unusually numerous or seriously sharp. Fig. 1 shows the general contour of the main line, Fig. 2 the original profile with uncompensated grades, and Fig. 3 the curvature on the 16.5 miles of heaviest grade.

In Fig. 4 is shown a map of the system including the electrified section. Fig. 5 is a general view of the power plant and Fig. 6 shows the general character of the country.

The productiveness of the country is quite varied in character: Coffee, corn, wheat, sugar cane, bananas, oranges and other semitropical grains and fruits grow in abundance. The soil and the climate seem well suited for a most successful agricultural development, and the possibilities for water-power development along the line of the railroad, combined with the many other attractive advantages, should leave little doubt as to the eventual prosperity of this section.

The section from Paso del Macho to Vera Cruz, 48 miles in length, is a gradual descent from an elevation of 1560 ft. to sea level, the ruling gradient being approximately 1.7 per cent and the alignment normal.

History

The promotion, construction and operation of this road, the first to be built in Mexico, has all been in close synchronism with the interesting, if tumultuous, history of the country. The original charter was obtained in August, 1855 under which a road was to be constructed from Vera Cruz, on the Gulf of Mexico, and across country *via* Mexico City to Acapulco, on the Pacific Coast. About 3½ miles of line extending from Mexico City to Guadalupe, a suburb, was built and opened to traffic on January 1, 1857. In August of the same year the original concession was taken over by Don Antonio Escondon, whose elder brother, Don Manuel Escondon, was the really dominant factor in the enterprise; but who, realizing that his advanced age would be likely to prevent his seeing the project completed, as was actually the case, placed his younger brother in direct charge of the undertaking.

In December, 1857, the services of Capt. Andrew Talcott, a graduate of West Point, of the class of 1818, with an extensive experience in government service and in the building of early American railroads, was engaged as chief engineer to take charge of the local tion and construction of the line.

Within 30 days Capt. Talcott was on the ground with three assistants and two brigades of engineers, consisting of 12 men each, and an exploring party of

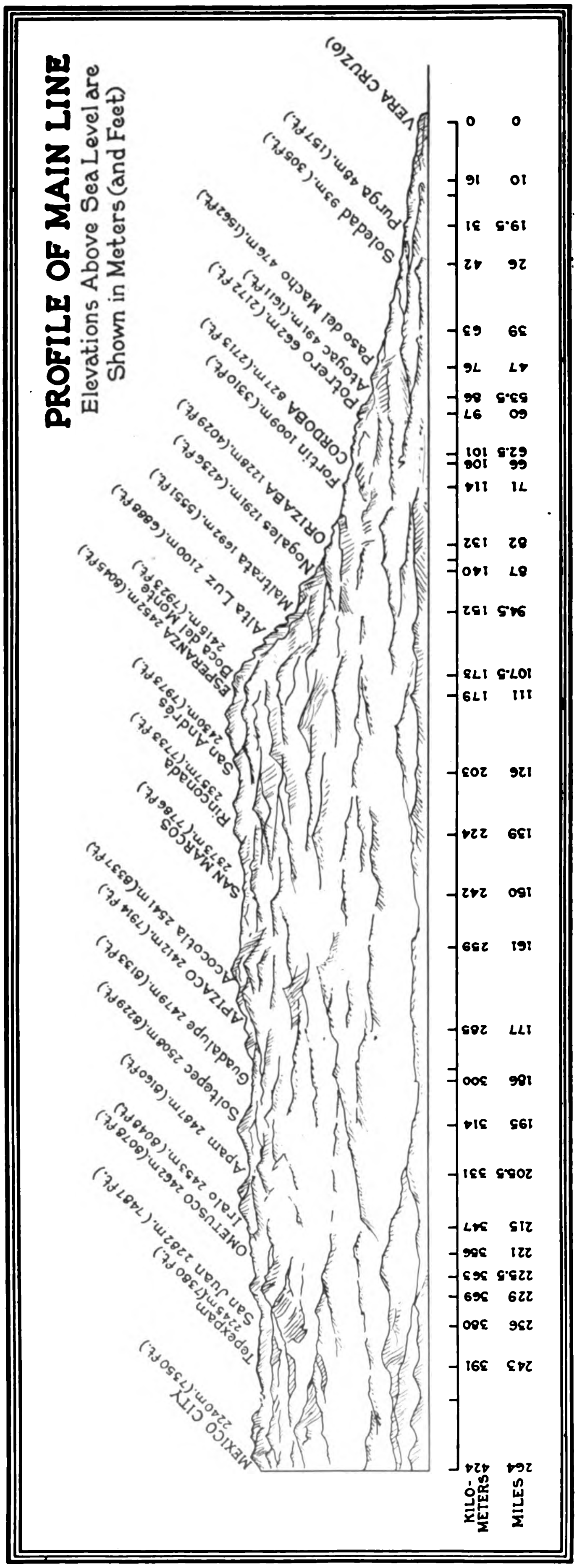


Fig. 1. Graphic Profile of Line Between Mexico City and Vera Cruz

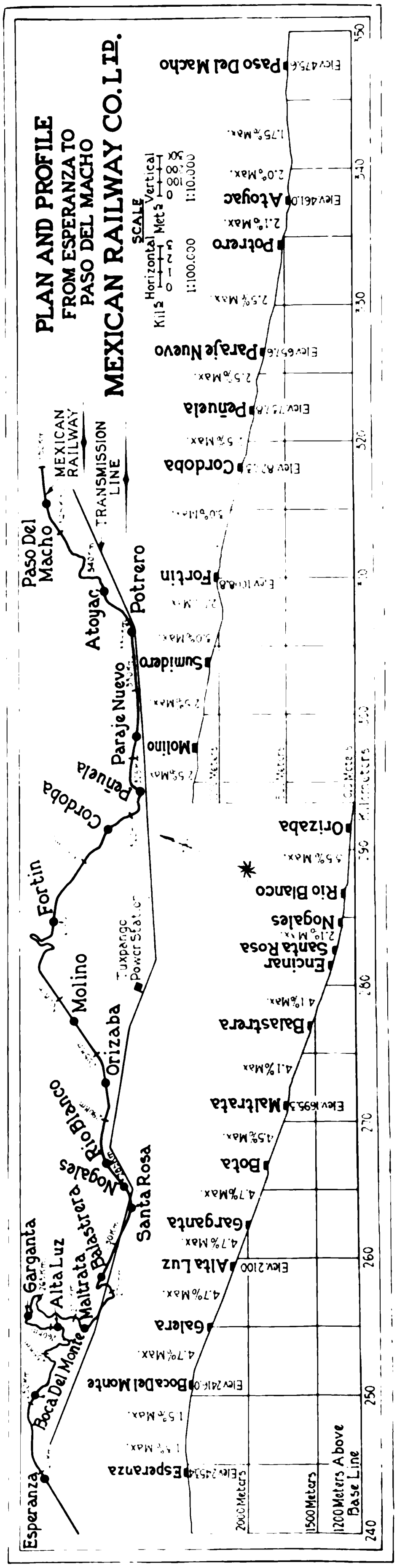

PLAN AND PROFILE
FROM ESPERANZA TO PASO DEL MACHO
MEXICAN RAILWAY CO. LTD.
SCALE
Horizontal Kils 0 1 2 3 1:100,000
Vertical Mets 0 100 200 300 1:10,000
MEXICAN RAILWAY
TRANSMISSION LINE
Tuxpango Power Station
Paso Del Macho
Atoyac
Potrero
Paraje Nuevo
Peñuela
Cordoba
Fortin
Molino
Orizaba
Rio Blanco
Nogales
Santa Rosa
Balastrera
Maltrata
Garganta
Alta Luz
Boca Del Monte
Esperanza
Elev.475.6 Paso Del Macho
1.75% Max.
2.0% Max.
Elev.461.0 Atoyac
2.1% Max.
Potrero
2.5% Max.
Paraje Nuevo
2.5% Max.
Peñuela
Cordoba
Fortin
Sumidero
Molino
2.5% Max.
Kilometers
Orizaba
4.5% Max.
Rio Blanco
Nogales
2.1% Max.
Santa Rosa
Encinar
4.1% Max.
Balastrera
4.1% Max.
Elev.1695.3 Maltrata
4.5% Max.
Bota
4.7% Max.
Garganta
4.7% Max.
Elev.2100 Alta Luz
4.7% Max.
Galera
4.7% Max.
Boca Del Monte
1.5% Max.
Esperanza
2000 Meters
1500 Meters
1200 Meters Above Base Line
240
250
260
270
280
290
300
310
320
330
340
350

Fig. 2. Profile of Electrified Section

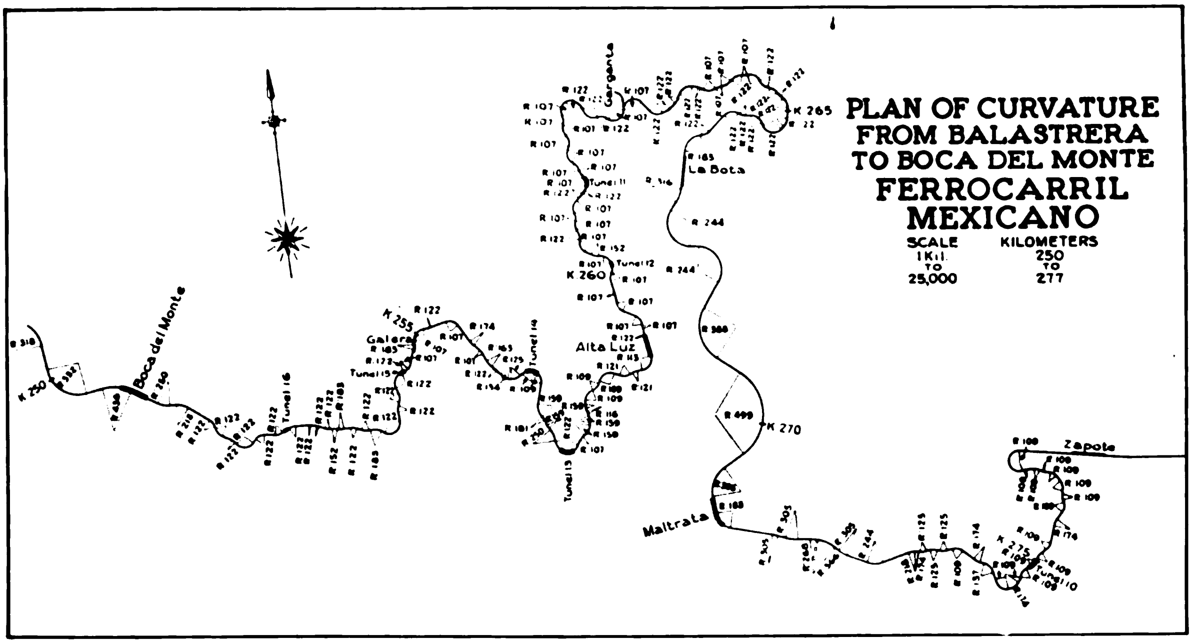

PLAN OF CURVATURE
FROM BALASTRERA
TO BOCA DEL MONTE
FERROCARRIL
MEXICANO
SCALE
1 Kil.
TO
25,000
KILOMETERS
250
TO
277
Boca del Monte
K 250
K 255
K 260
K 265
K 270
K 275
Galera
Tunel 15
Tunel 16
Tunel 14
Tunel 13
Tunel 12
Tunel 11
Alta Luz
Gargantа
La Bota
Maltrata
Zapote

Fig. 3. Plan of Curvature from Balastrera to Boca Del Monte on the Ferrocarril Mexicano

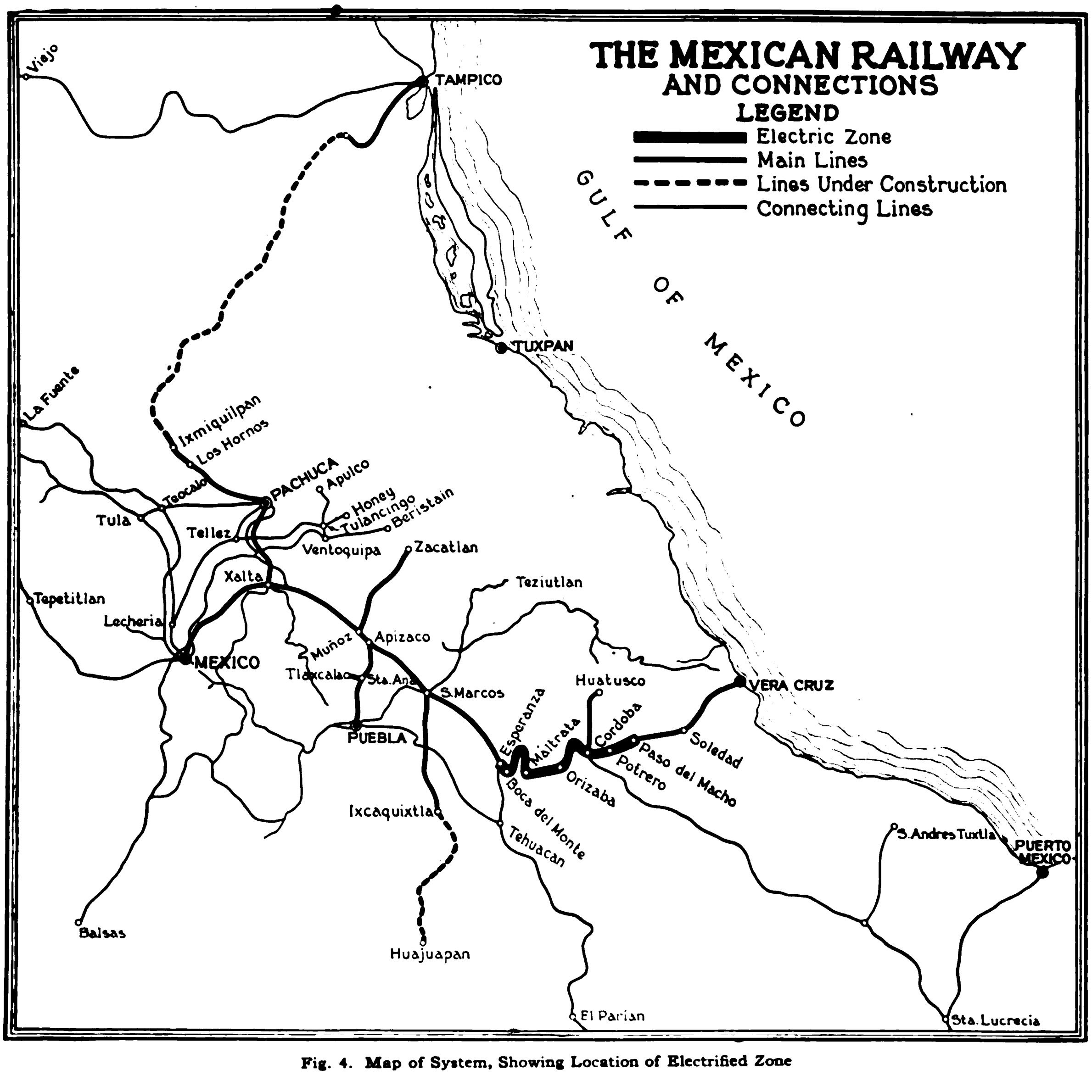

THE MEXICAN RAILWAY
AND CONNECTIONS
LEGEND
Electric Zone
Main Lines
Lines Under Construction
Connecting Lines
GULF OF MEXICO
Viejo
TAMPICO
TUXPAN
La Fuente
Ixmiquilpan
Los Hornos
Teocalo
PACHUCA
Apulco
Honey
Tulancingo
Beristain
Tula
Tellez
Ventoquipa
Zacatlan
Xalta
Teziutlan
Tepetitlan
Lecheria
MEXICO
Muñoz
Apizaco
Tlaxcala
Sta. Ana
S. Marcos
Huatusco
VERA CRUZ
PUEBLA
Esperanza
Maltrata
Cordoba
Paso del Macho
Soledad
Potrero
Orizaba
Boca del Monte
Tehuacan
Ixcaquixtla
S. Andres Tuxtla
PUERTO MEXICO
Balsas
Huajuapan
El Parian
Sta. Lucrecia

Fig. 4. Map of System, Showing Location of Electrified Zone

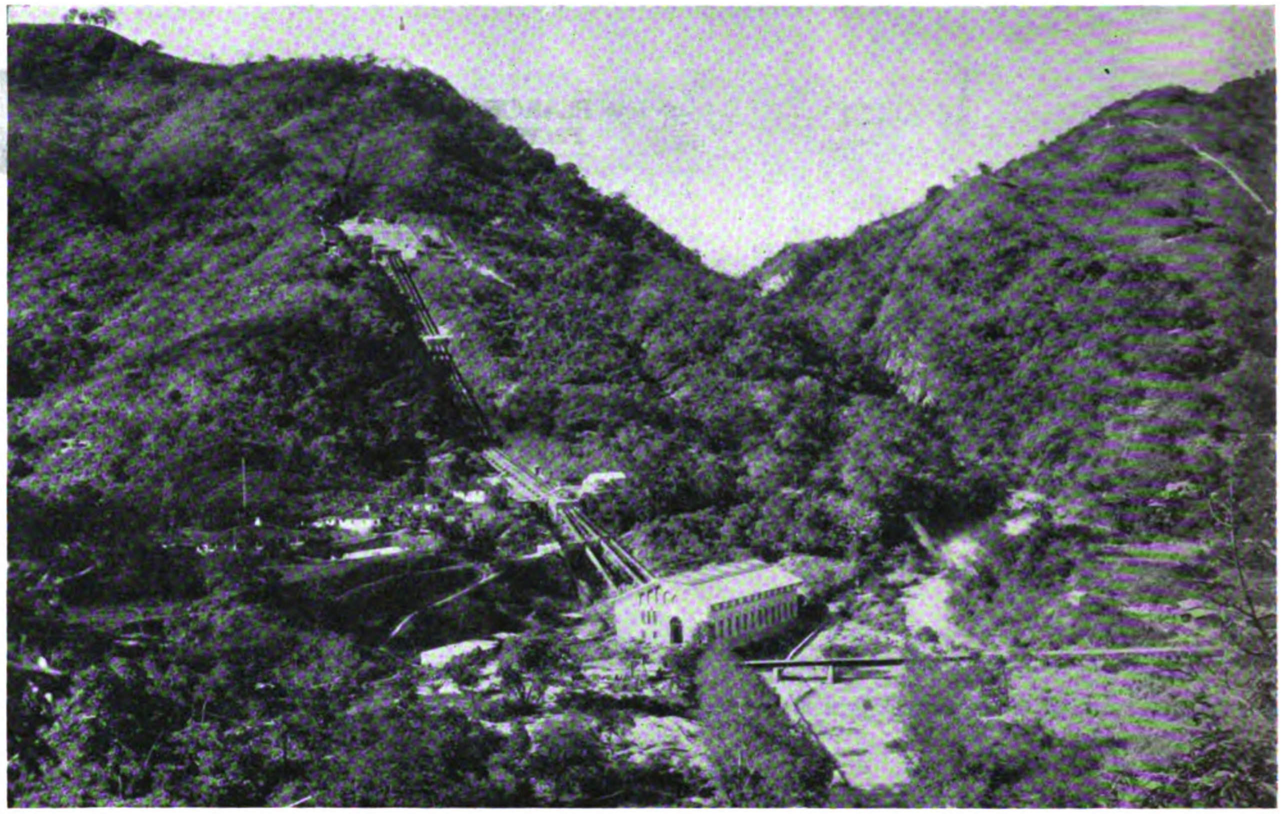


Fig. 5. Tuxpango Power Plant, which Supplies Power to the Mexican Railway

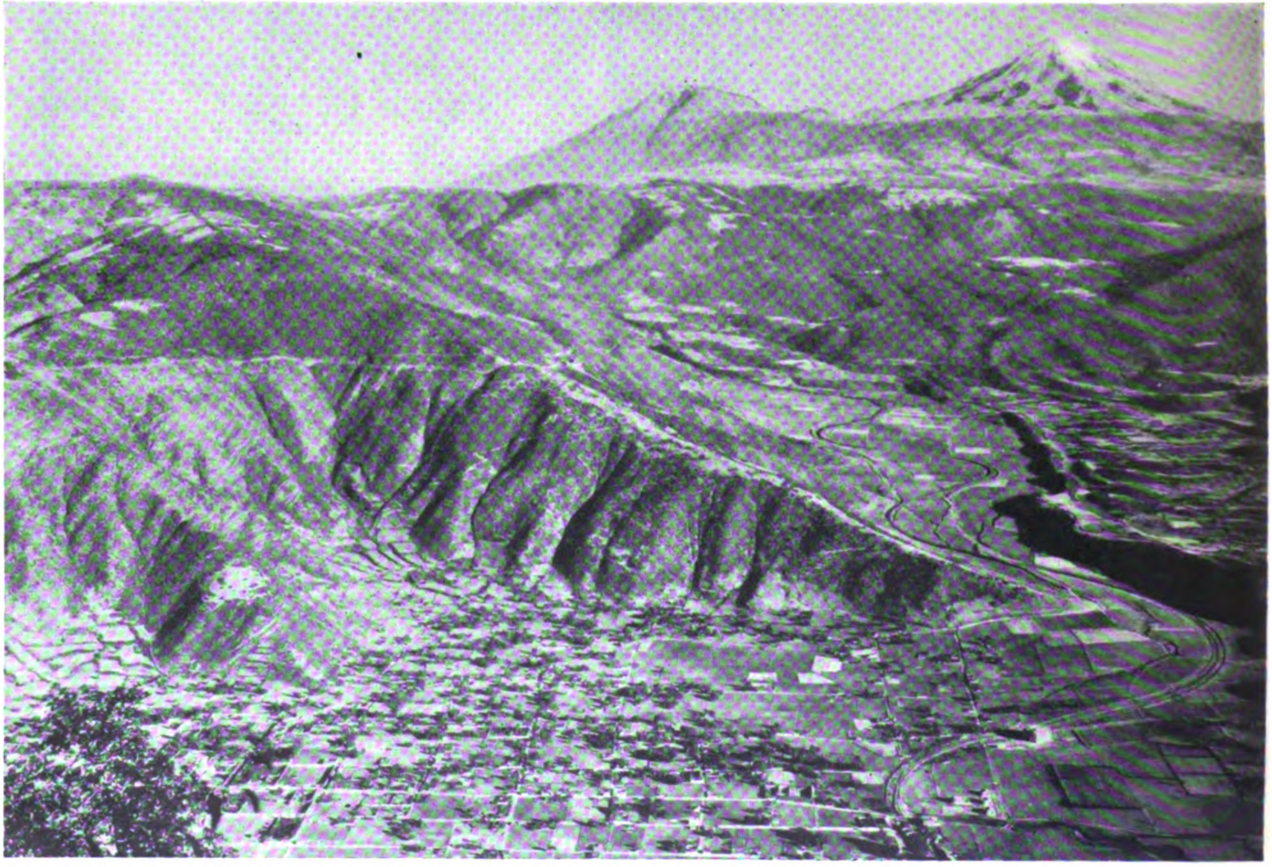


Fig. 6. General Fanoramic View of Electrified Section

five men ready for work. However, before the survey had been well started an internal revolution overthrew the constitutional government resulting in a struggle between the contending parties which seriously retarded the work. So it was not before March, 1859, that Capt. Talcott forwarded his report covering the survey of the route and the estimated cost of construction, maintenance, and operation of a railway from Vera Cruz to Mexico City.

Much careful work was done in determining the location of the line between Encinar and Boca del Monte. The route surveyed was approximately 19 miles in length, though the surface of the country was favorable for a considerably longer route, which would have reduced the ruling grade, but at an increased cost of construction. The question was analyzed from a purely economical standpoint. More tons could be handled with the same motive power if the grade was reduced and the cost of fuel per ton-mile would be less; but the longer line would cost more to construct and the maintenance of the line would be greater. It was desired to find the point which would secure the minimum cost of operation. It is interesting to note that a locomotive weighing 25 tons, with a tender weighing 20 tons, loaded, was considered in these calculations; one such locomotive being thought capable of hauling a 130-ton train from Vera Cruz to Orizaba. With a second engine of equal weight, but specially constructed for helper service, a train of the same weight could be taken from Orizaba to Boca del Monte.

It was considered that the most economical grade, so far as working power was concerned, changed as the adhesion of the locomotive changed, and that the adhesion varied from 14 per cent to 30 per cent, also that with an adhesion of 30 per cent a grade of 2.9 per cent would be most economical; or that with an adhesion of 20 per cent a grade of 2.3 per cent would be most economical; or that with adhesion of 14 per cent a grade of 1.9 per cent would be preferable. Increasing the grade to 4.6 per cent was estimated to increase the cost of power only 7.2 per cent with an adhesion of 20 per cent; that is to say, as the adhesion diminishes the cost of working increases.

The maintenance of way was considered at that time usually to be as large an item of operating expense as that of power, and therefore the most economical operation would be obtained by a grade exceeding that which would cost least for power, even if the cost of construction were not less. It was estimated that in a mountain road of this kind, a grade of 4.6 per cent would be 10 per cent shorter, and the cost of construction less; and that the saving in cost, together with the saving in maintenance, would fully compensate for the additional power required for operation. The extent of the saving would depend on the amount of tonnage which would be taken over the line. The line was, therefore, surveyed to have a ruling grade of approximately 4.6 per cent.

For many months after Capt. Talcott's report had been made no definite action was taken because of the internal conditions of the country. No construction work was done under the grant of August 31, 1857. A new grant was obtained from the existing government on April 5, 1861, and Capt. Talcott was called on to return to Mexico, which he did in March, 1862.

In the meantime, owing to the unsettled conditions of the Mexican Government, there had been a joint intervention in Mexican affairs by European powers, and Spanish soldiers had been put in charge at Vera Cruz in December, 1861; and these were soon followed by French troops. By this time about 9 miles of track had been constructed between Vera Cruz and Tejeria, from which point transportation to Mexico City and intervening settlements was conducted on the old Spanish highways, which had been allowed to deteriorate until almost impassable during the rainy season. The French army, requiring improved transportation, seems to have been responsible for the further extension of the tracks from Tejeria to Soledad. This definitely determined the route via Orizaba. The arrival of Maximilian in Mexico City in June, 1864, gave impetus to negotiations that Antonio Escondon had under way with English capitalists, which finally resulted in a contract, dated August 19, 1864, between the Imperial Railway Co., Ltd. and Smith Knight & Co., for the construction of a railway from Vera Cruz to Mexico City and a branch railway to Puebla, according to the plans and specifications of Capt. Talcott. Immediately afterward, definite plans for energetic construction of the remainder of the road were begun; the terms of the transfer of the road calling for its completion by April, 1869.

The present Mexican Railway was incorporated August 20, 1864 as the Imperial Mexican Railway Company, Ltd., under the government of Emperor Maximilian I.

After the downfall of Maximilian in 1867, and the reëstablishment of the republic, it was necessary to revindicate the former concessions. Accordingly on November 27, 1867, a new contract was made with Senor Escandon on terms more favorable than were contained in the former contract.

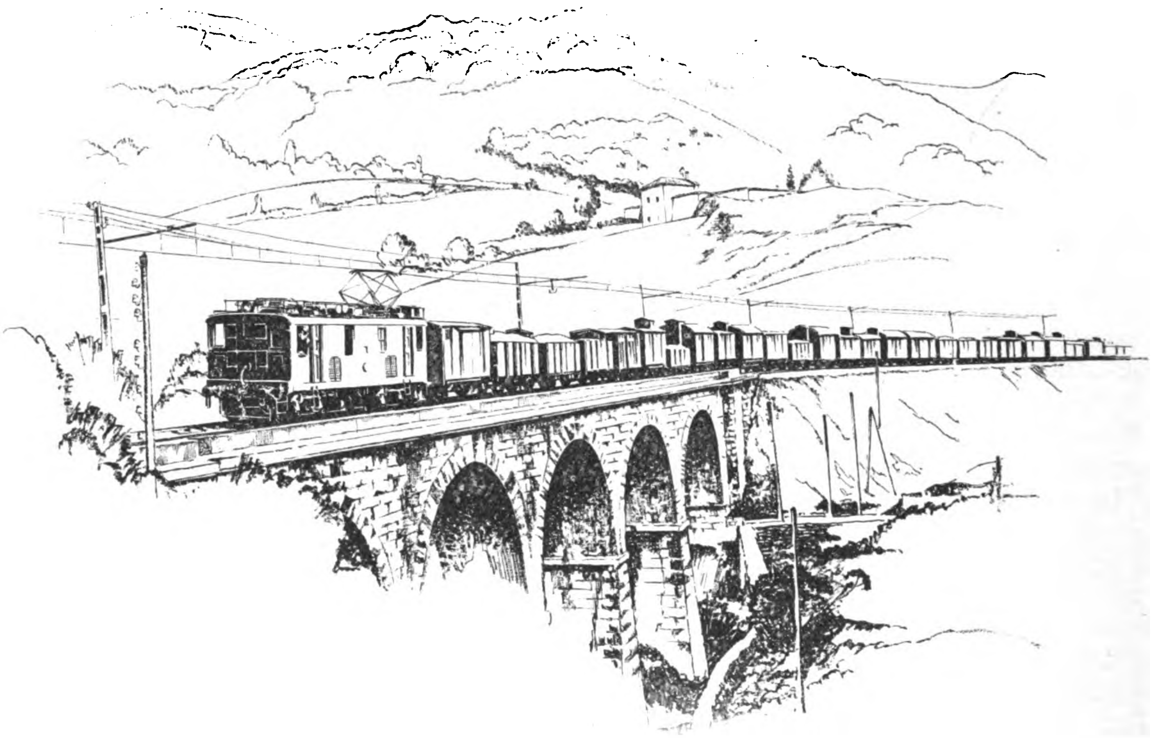
The railroad was finally completed on December 31, 1872, under the Escandon grant, 9 years after his first contract was made and 18 years from the date of the original concession. The road was formally inaugurated and opened for through traffic on January 1, 1873, by President Sebastian Lerdo de Tejada. The cost of construction was unusual and extremely high. The road had thus been in operation for about 51 years previous to the electrification of the Mountain Division which is the subject of this article.

With the comparatively settled conditions which gradually came about with the ascending of Porfirio Diaz as president, the property became more prosperous. Before the beginning of the disturbance leading to his abdication the property had been brought into splendid condition. However, the revolution of 1910 suddenly brought an end to this prosperity and resulted in the road being taken from its owners for operation by the new government in November, 1914, under which control it remained for about five years; first until August, 1916, when it was returned, but was again seized in April, 1917 and not returned until June, 1920.

When the property was returned to the owners the line and the equipment were found to be in very poor condition, as practically no new apparatus or supplies had been purchased and the stores had been depleted. Seventeen stations along the line had been burned or seriously damaged and the old personnel of the organization had been dispersed and the discipline of the working forces had become much demoralized. On again taking charge of the road in 1920 the owners found many of the locomotives and cars to be in an inoperative condition and there was little material or supplies on hand with which to make repairs. New difficulties were also encountered in the nature of strikes, which added greatly to the already difficult task of handling the increasing traffic.

In the fall of 1921 the business on the railway reached a point where it became very difficult to get the traffic over the mountain division from Orizaba to Esperanza which had always been the proverbial bottle neck. On October 25, a total of 14 trains, two of which were passenger, an aggregate of 4648 tons, was taken up the mountain, establishing a record for the division and indicating that the economic capacity of the single-track line with existing type of motive power had been reached.

(*To be continued*)



Experimental Solutions of Electrostatic Problems

PART I: MEASUREMENT AND COMPUTATION OF CHARGE

By DR. JOHN LABUS
Electrical Laboratory, Union College, Schenectady, N. Y.

THE main reason for the rapid advance of electrical science is that, largely due to Maxwell, a very complete mathematical theory of almost all electrical problems has been developed. Another and almost as important reason is that electrical phenomena can be observed and recorded by instruments in a far better and easier way than the phenomena in any other branch of engineering.

There are, however, a number of problems in which a purely mathematical analysis practically fails, because of the complicated nature of the work. In such cases it is often desirable to replace a part of the computation by experimental work and so to combine mathematical analysis with the results of the measurement. This, however, does not mean that the importance of pure theory should be underrated. Usually, the theory gives the hint to the performance of the experiment; and, generally speaking, experiments should be resorted to if the theory becomes too complicated.

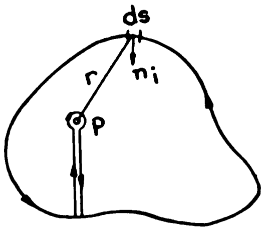


Fig. 1. Elementary Diagram for Determination of Charge in Region Surrounding Point *P*

The solution of Laplace's equation or the determination of the electric field and the potential inside a given region which is free from electric charges lends itself to partly theoretical and partly experimental work. Indeed, it is in almost all cases occurring in practice the only method of procedure, as the writer has found after many endeavors to get solutions in a purely theoretical way.

The object of this investigation was to find a practical means of determining the potential of an electric field containing no real charges. The solution is obtained partly from simple tests, easily made, and partly from a mechanical integration, taken over the boundary of the electrical field (Fig. 1), where a certain distribution of potential is given. The procedure is perhaps best shown by referring to Fig. 2. The heavy line represents the cross section of certain strips, perpendicular to the paper, thus forming the boundary of the region to be investigated. In this way the two-dimensional problems are considered; but the method also applies to fields which are symmetrical with respect to one of the three axes. The point *P* at which the field is to be determined represents a perpendicular thin wire. Disregarding first the given distribution of the potential along the boundary, we apply an a-c. voltage between this wire and the grounded boundary and measure, by means of a suitable ammeter (*A*), the charging current flowing from the wire to the individual strips. After the performance of this experiment, the potential V_P at *P* is found by

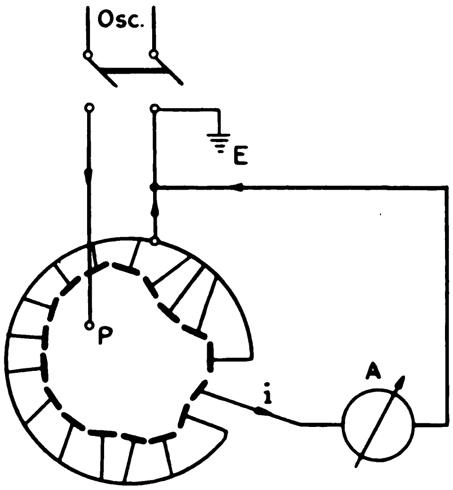


Fig. 2. Schematic Plan of Connections and Apparatus for Determining Distribution of Charge at Boundary Surrounding a Perpendicular Wire at *P*

$$V_P = \text{Constant} \sum_{1}^{N} V_b \, i\Delta \tag{1}$$

Where V_b is the given potential at the boundary in the particular problem considered, i the charging current observed in the experiment, and Δ the width of the strips. The sum is to be taken over all N strips.

Considering Equation (1) it becomes evident that if, for a given region, the results of the experiments mentioned above are known the solution can be found easily by mechanical integration, no matter what the distribution of the potential (V_b) at the boundary is. There are of course many applications for this method. A practical case is, for instance, to find the potential at points outside of a transformer winding, due to the potential difference between the beginning and the end of the winding in respect to ground. While in the case of a mathematical solution, the problem must be computed generally, this method is most conveniently applied to the most important points of the electric field, disregarding the others.

In order to explain the method, reference is made to a relation which is known as Green's theorem, *viz.:*

$$4\pi V_P = \int_s V_b \frac{\partial G}{\partial n_i} \cdot ds \qquad (2)$$

G denoting Green's function, $\frac{\partial G}{\partial n_i}$ its derivative with respect to the inside normal at the boundary and ds a line element. The contour integral is taken over the boundary S.

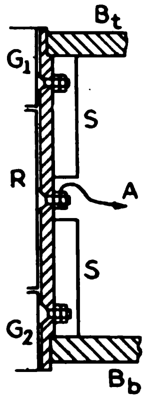


Fig. 3. Detail of One of the Elements Composing Boundary at which Charge is Determined

G_1, G_2, and R are sections of tin foil, R being the measured section, G_1G_2 forming guard rings; B_t and B_b are sections of boards establishing boundary; S indicates the shield; and A is the current lead.

According to the theory given at the end of this article, Green's function has a physical meaning: it is the potential at any point of the region, if a charge $Q=1$ be placed at another point P, the boundary being kept at zero potential. Green's function therefore depends in addition to the coördinates of a certain point, also on a parameter, represented by the coördinates of another point P. With respect to Equation (2), it is evident that, in order to determine the potential at the point P, we do not need Green's function itself; what we are interested in is its derivative along the boundary. (In the event that the problem is computed by pure analysis, Green's function must be calculated first and then differentiated). If by definition, however, G is a potential, then $\frac{\partial G}{\partial n_i}$, the slope or gradient of the potential is nothing else than the density of the electric field and

$$q = \frac{1}{4\pi} \cdot \frac{\partial G}{\partial n_i} \qquad (3)$$

represents the charge per unit length at the boundary, if a unit charge be placed at a point P within the region, the boundary being grounded.

In order to measure the charges referred to along the boundary, the latter is split up into a number of strips, as is shown in Fig. 2 which is a plan view of the arrangement. These strips, made of wood or of any suitable insulating material, are covered on one side with tin foil glued on in sections. The details are to be seen in Fig. 3, which is a cross-section of a strip. As the field considered must be uniform in the perpendicular direction, the set is provided with two guard rings at both sides of the middle section, the charge of which is measured, thus excluding the end effect. Hence every strip has three tin foils, separated by small air gaps. In this way the average value of the charge along the strip is measured. Instead of being a continuous curve, the plot of the values thus obtained is a step line. The smaller the width of the strips, the smoother the curve will be.

The strips by which the given region is built up are supported by a frame with a top and a bottom board (B_t and B_b in Fig. 3). Into these boards the shape of the boundary is cut out and then the strips are fixed on to conform to its outline. The middle section of each strip is connected to a dial, by means of which all strips can be grounded, except one at the time, which is connected to the ammeter (A) (Fig. 2). The tin foils forming the guard rings are permanently connected together and grounded. The measurement is performed with alternating current, thus measuring the displacement current, being proportional to the charge. The thin wire at P is connected to one pole of an oscillator (Fig. 2). All the strips, except one, are connected to the other grounded pole. This arrangement introduces no error, except in so far as the small voltage drop across the ammeter is concerned, which prevents bringing the potential of the strips exactly to zero. This error however is a very small one, because this voltage drop is negligible compared with the total voltage between P and the boundary. In the instances to be shown later, it does not exceed 0.02 volt, while the total voltage is about 24 volts.

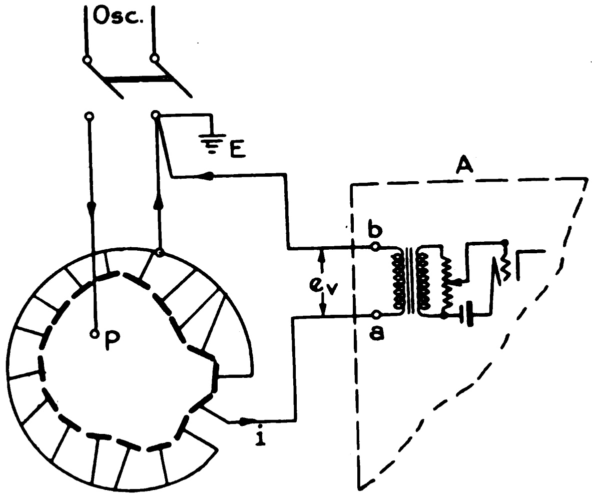


Fig. 4. Diagram of Connections for Measurement of Charges by Use of Heisingvoltmeter

Another way to measure these charges would be by the ballistic method; but either a very high voltage or the use of regions of very small dimensions would apparently be necessary, thus decreasing the accuracy of the measurement.

Measurement of $\frac{\partial G}{\partial n_i}$

In all the following measurements a frequency of 1000 cycles was used. The calibrated oscillator generated a voltage of about 24 volts. The small charging currents of about 10^{-8} amp. were measured by means of a tube voltmeter containing four tubes (Heisingvoltmeter). This was suitable for measuring voltages between 0.001 and 3.16 volts r.m.s. and currents between 0.02 and 31.6 milliamperes r.m.s. An attempt to use the instrument directly as an ammeter failed, because the currents to be measured were below its range. An effort was then made to use a tube, sending the current to be measured through a resistance across its grid. The voltage of the plate circuit was connected to the input terminals of the Heisingvoltmeter. This method however failed likewise, the charging current flowing between grid and filament being large compared with the unknown current. At last the following method proved to be successful: The strip, the charging current (i) of which is desired is connected in series with the input transformer of the Heisingvoltmeter, as in Fig. 4, so that it becomes the magnetizing current of this transformer. The voltage (e_v) thus obtained across the terminals ab was within the range of the tube voltmeter and could be measured easily.

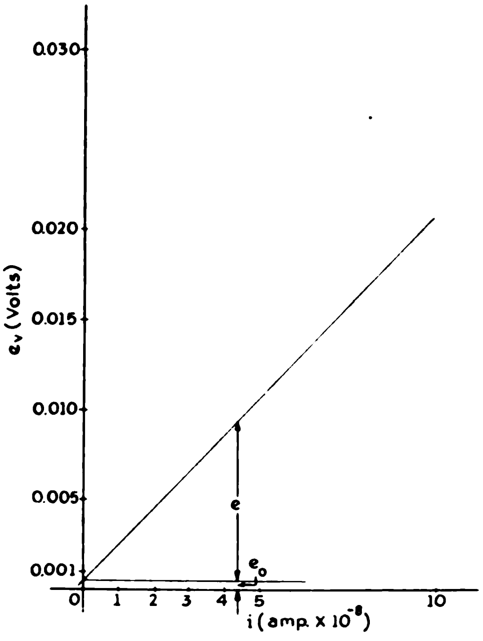


Fig. 5. Calibration Curve, Showing Straight-line Relationship Between Charging Current (i) and the Potential (e_v) Across Terminals of Input Transformer of Heisingvoltmeter

A calibration of this arrangement showed a perfect linear relation between i end e_v, such as that shown in Fig. 5. For this purpose a cylindrical boundary (Fig. 6) built up of 25 strips in a manner similar to that shown in Fig. 7 was used, since its capacity can be accurately calculated. The point P was at the center of the cylinder. The dimensions were:

Inner diameter $(d) = 8.1$ cm.

Active length (without guard rings) $(h) = 11.0$ cm.

Diameter of the perpendicular wire at P:

$\delta = 0.025$ cm.

Therefore the total capacity of the cylinder:

$$C_T = \frac{h}{2 \log_e \left(\frac{d}{\delta}\right)} = \frac{11}{2 \log_e \left(\frac{8.1}{0.025}\right)} = 0.9575$$

and per strip $c = C/25 = 0.0383$

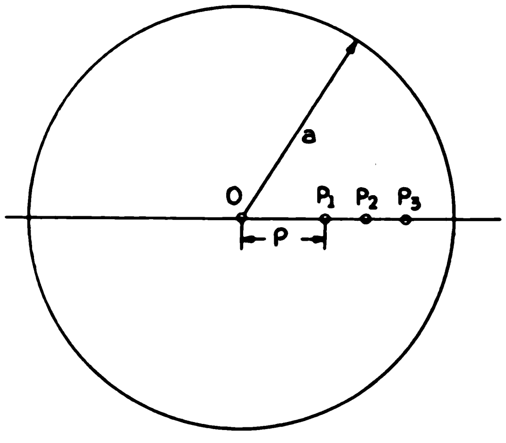


Fig. 6. Diagram Showing Locations of Point P for Successive Measurements of Charge Distribution at a Circular Boundary

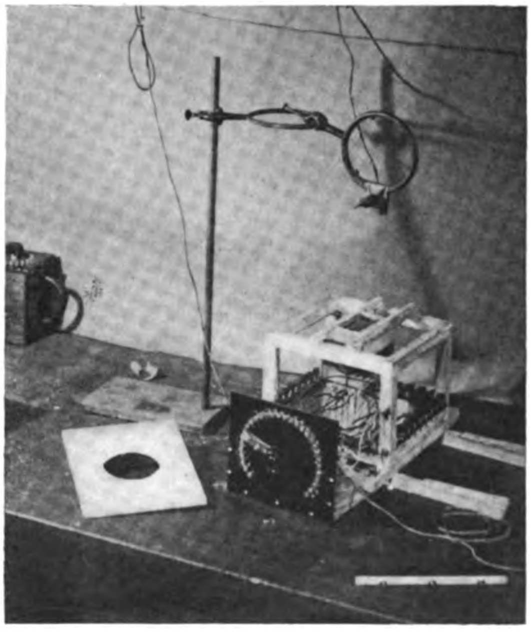


Fig. 7. A Laboratory Set-up for the Measurement of Charge

Knowing the applied voltage $(E) = 24$ volts, we can calculate the charging current of a certain number (x) of strips:

$$i = \frac{dq}{dt} \quad \text{or} \quad I_x = \omega E C_x$$

whereby I and E represent the peak values, $\omega = 2\pi f$ (f = frequency) and $C_x = xC$.

Hence:

$$I_x = 2\,\pi\,1000 \times 24 \times \frac{0.0382}{9 \times 10^{11}}\,x = 0.64 \times 10^{-8}\,x \text{ amp.}$$

Fig. 5 shows the obtained relation between i and e_v.

In order to prevent radiation, all leads consisted of copper shielded wire. Furthermore, the frame supporting the strips was shielded by metal plates; and, inside the frame, the strips were shielded (S in Fig. 3) to prevent radiation through the cracks between the strips. In spite of these precautions, Fig. 5 shows a constant value of e_v at $i=0$, caused by still remaining radiation affecting the wires which connect the strips with the dial. In the following practical example it will be shown how this additional value (e_o) can be determined and eliminated in the results.

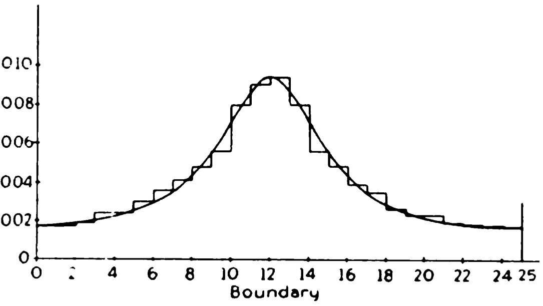


Fig. 8. Chart of Calculated and Measured Charge at Boundary of a Circle (Fig. 6) for P_1, Where $\rho/a = 0.4075$

The method has been applied to fields of two configurations: the circle and the rectangle; and test results have been compared with the calculated values.

The potential at a certain point inside a circle, given by its polar coördinates ρ and ϕ, can be calculated by Poisson's formula:

$$V_P = \frac{1}{2\pi}\cdot\int_o^{2\pi} V(\psi)\,\frac{a^2-\rho^2}{a^2-2\,\rho\,a\cos(\phi-\psi)+\rho^2}\cdot d\psi \qquad (4)$$

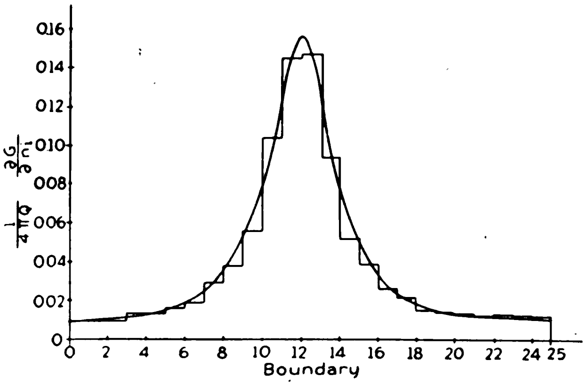


Fig. 9. Charge at Boundary of a Circle for P_2, Where $\rho/a = 0.605$

where $V(\psi)$ denotes a given distribution of potential along the circumference of the circle, a being the radius of the circle.

Since in our experiment the charge Q at the point P is different from unity, Green's theorem must be written:

$$V_P = \frac{1}{4\pi Q}\int_o^{2\pi} V(\psi)\,\frac{\partial G}{\partial n_i}\,a\,.\,d\psi \qquad (5)$$

wherein $a.d\psi$ is substituted for ds.

Comparing Equations (4) and (5), we get for the circle:

$$\frac{1}{4\pi Q}\,\frac{\partial G}{\partial n_i} = \frac{1}{2\pi a}\cdot\frac{a^2-\rho^2}{a^2-2\,\rho\,a\cos(\phi-\psi)+\rho^2} \qquad (6)$$

Here $\frac{\partial G}{\partial n_i}$ is the electric field at the boundary, and since the width of the strips is 1 cm., $\frac{1}{4\pi}\,\frac{\partial G}{\partial n_i}$ is the charge per strip. As already mentioned, the voltage (e_v) measured across the input terminals of the Heisingvoltmeter minus the constant value e_o (caused by radiation) is proportional to this charge, or the corresponding displacement current. Therefore:

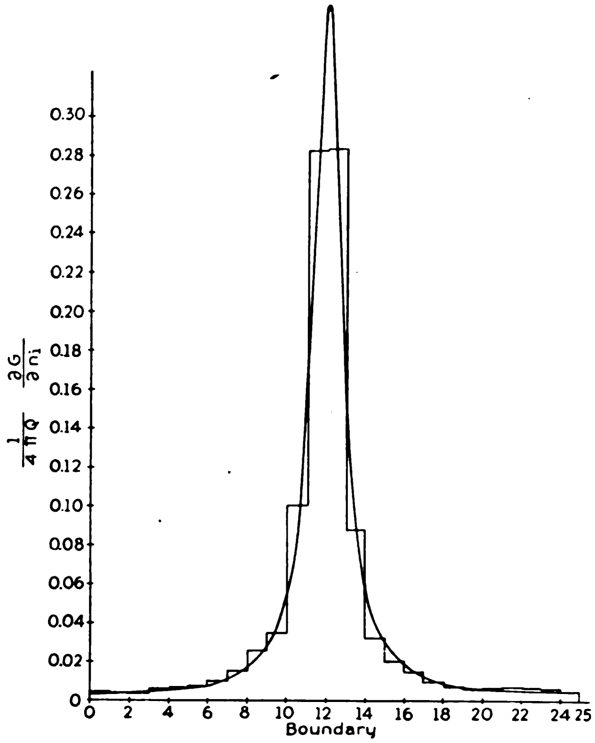


Fig. 10. Charge at Boundary of a Circle for P_3, When $\rho/a = 0.802$

$$e = e_v - e_o = \text{Const}\times q = \text{Const}\times\frac{1}{4\pi}\,\frac{\partial G}{\partial n_i} \qquad (7)$$

Furthermore, the sum of the partial charges (q), taken over all N strips, is equal and negative to the charge (Q) bound on the wire at P. Disregarding the sign, it assumes

$$\sum_1^N e = \text{Const}\sum q = \text{Const}\times Q \qquad (8)$$

Dividing Equations (7) and (8), we obtain the important relation

$$\frac{e}{\sum e} = \frac{1}{4\pi Q}\,\frac{\partial G}{\partial n_i} = \frac{e_v-e_o}{\sum(e_v-e_o)} \qquad (9)$$

It may be noticed that the right-hand side of this equation, as well as the right-hand side of Equation (6), no longer contains the (unknown) charge Q.

The voltage e_o, which is assumed to be the same for all strips, is determined as follows: After having measured the N values of e_v, we add them. Then we connect all the strips together and measure the total charging current of the boundary of the range, e_N being the measured voltage at the Heisingvoltmeter. The value thus obtained is always a little smaller than the sum Σe_v, though it should be the same. The difference is due to the remaining radiation; and

$$e_o = \frac{(\Sigma\, e_v - e_N)}{N} \qquad (10)$$

represents the constant value which must be subtracted from e_v in order to get e.

In the case of the circle investigated, $(\Sigma e_v - e_N) = 0.016$ volt which, divided by $N = 25$, gives $e_o = 0.00064$ volt, which value is almost the same, no matter what the position of P is. If the set (Fig. 7) had been built up by a trained mechanic, it is reasonable to suppose that the remaining radiation, and therefore e_o would become still smaller and perhaps would not need to be taken into further account. This holds also, as far as the general accuracy is concerned; though, to be sure, the agreement with the calculated values seems very satisfactory, even with the rather crude model.

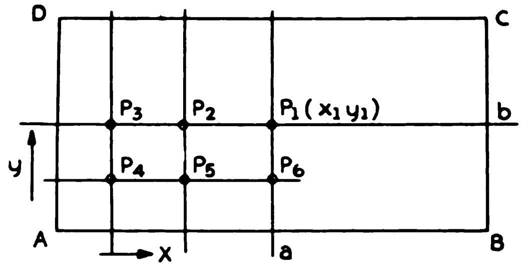


Fig. 11. Diagram of Successive Locations of Point *P* for Measurements of Charge at a Rectangular Boundary

In the way described, the distribution of $\frac{1}{4\pi Q}\,\frac{\partial G}{\partial n_i}$ along the circumference of the circle (Fig. 6) was successively measured for $\rho = 1.65$, 2.45, and 3.25 cm.; or since the radius of the circle $a = 4.05$ cm., $\rho/a = 0.4075$, 0.605, and 0.802 respectively. In Figs. 8, 9, and 10, the values of $\frac{1}{4\pi Q}\,\frac{\partial G}{\partial n_i}$, evaluated by Equation (9), are plotted against the boundary, thus forming the step line, the width of the steps being the width (1 cm.) of the strips. The continuous curves represent the calculated values from Equation (6).

A similar investigation was performed with a rectangle (Fig. 11) for the points P_1 to P_6, with the results shown in Figs. 12 to 17. The computation (1) gives:

$$\frac{1}{4\pi Q}\,\frac{\partial G}{\partial n_i} = \frac{2}{a}\sum_{1}^{\infty} \frac{\sin\dfrac{n\pi x}{a}\sin\dfrac{n\pi x_1}{a}\sinh\dfrac{n\pi}{a}\,(b-y_1)}{\sinh\dfrac{n\pi b}{a}} \qquad (11)$$

The notations in this equation are explained by Fig. 11. Even in this simple case the numerical evaluation of the result given by Equation (11) takes longer than the performance of the experiment, not to speak of the general computation of the problem.

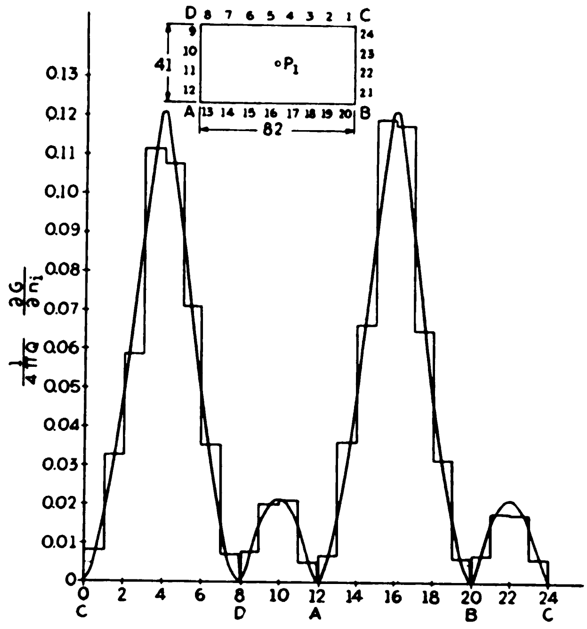


Fig. 12. Chart of Calculated and Measured Chart at Boundary of a Rectangular Region (Fig. 11) for *P*₁ (41, 20.5)

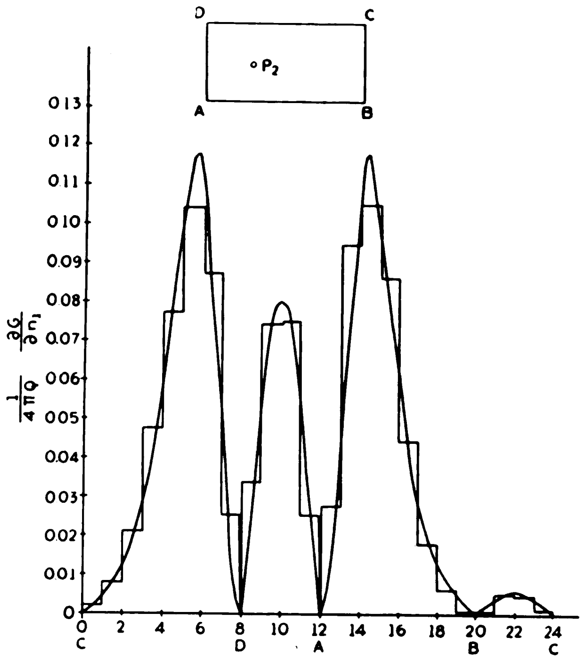


Fig. 13. Charge at Rectangular Boundary for Point *P*₂ (24, 20.5)

In order to give an example of the application of Equation (2), it is assumed that the side AB of the investigated rectangle is held at a potential $V_b = E$, while the other sides are grounded $(V = 0)$. The values of V thus obtained are plotted in Fig. 18 for some planes which are parallel to the sides a and b.

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(1) J. J. Smith: *Journal of the Franklin Institute*, Oct., Nov., Dec., 1925.

These simple examples have been chosen because they can be checked by the theory. The method however is applicable to, and finds its usefulness in regions of more complicated shape and of correspondingly more intricate potential distribution at the boundary.

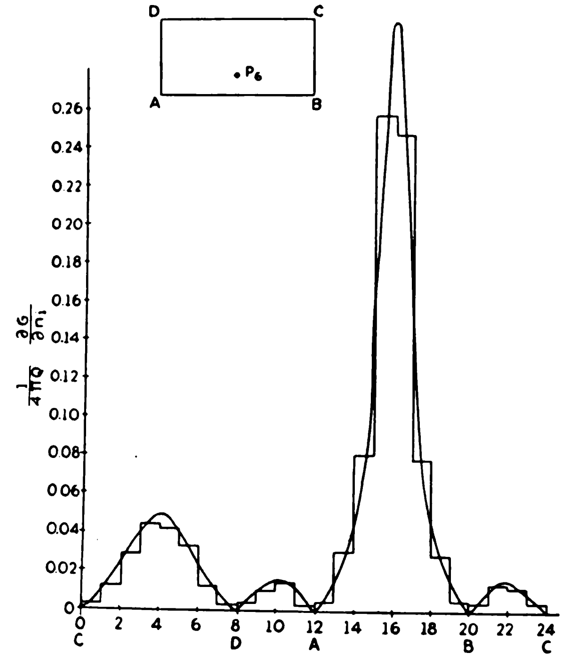

Fig. 14. Charge at Rectangular Boundary for Point P_6 (41, 10)

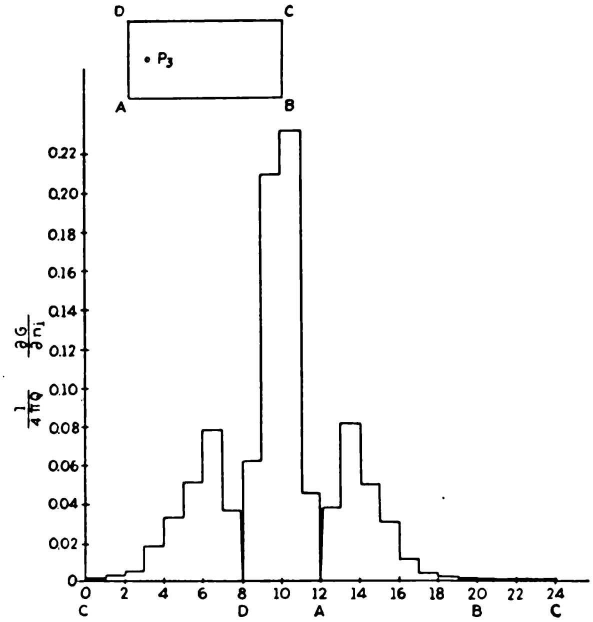

Fig. 15. Chart of Measured Charge at Rectangular Boundary for Point P_3 (10, 20.5)

For the sake of completeness, a short derivation of Equation (2), is given:

Gauss's theorem

$$\int\int \operatorname{div} F \, d\tau = \int F_n \, ds \qquad (12)$$

is the relation between the flux $\int F_n \, ds$, passing the boundary of a given region and the divergence of the electric field inside the region. Provided U and V are scalar functions of the coördinates, we substitute for the vector F

$$F = U \operatorname{grad} V$$

According to a relation known to students familiar with vector analysis

$$\operatorname{div}(U \operatorname{grad} V) = \operatorname{grad} U \operatorname{grad} V + U \operatorname{div} \operatorname{grad} V$$

Therefore we get by substituting in Equation (12):

$$\int\int (\operatorname{grad} U \operatorname{grad} V + U \operatorname{div} \operatorname{grad} V) \, d\tau$$

$$= \int U \operatorname{grad} V \, ds = -\int U \frac{\partial V}{\partial n_i} ds \qquad (13)$$

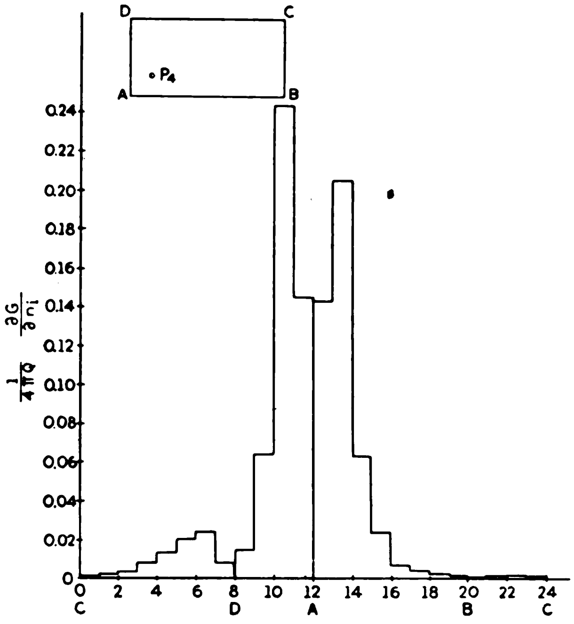

Fig. 16. Chart Measured of Charge for Point P_4 (10, 10)

where n_i denotes the inside normal at the boundary; ds is the line element, and $d\tau$ an element of area of the region. A similar equation is obtained by interchanging U and V in Equation (13). Subtracting both equations, we get another one, *viz.*:

$$\int\int (V\nabla^2 U - U\nabla^2 V) \, d\tau = \int \left(U\frac{\partial V}{\partial n_i} - V\frac{\partial U}{\partial n_i}\right) ds \qquad (14)$$

which is spoken of as Green's theorem in its second form. The symbol ∇^2 denotes Laplace's operator: $\operatorname{div} \operatorname{grad} = \nabla^2 = \Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$.

Starting from this equation, we shall attempt to compute the potential V_P at any point P inside the given region (Fig. 1) at the boundary of which a certain distribution of potential is given. If we assume, as is the case, that the space is free from charges, then Laplace's equation applies, or

$$\nabla^2 V = 0$$

Now we define a function G within the region considered, such that:

(1). The function (G) is harmonic within the condered region, with the exception of a single point P; *i.e.*, G is a solution of Laplace's equation $\nabla^2 G=0$

(2). If r is the distance from the point P, the function $(G-2 \log r)$ is harmonic throughout the whole region, or $\nabla^2 (G-2 \log r)=0$, where P is included.

(3). At the boundary, G is zero.

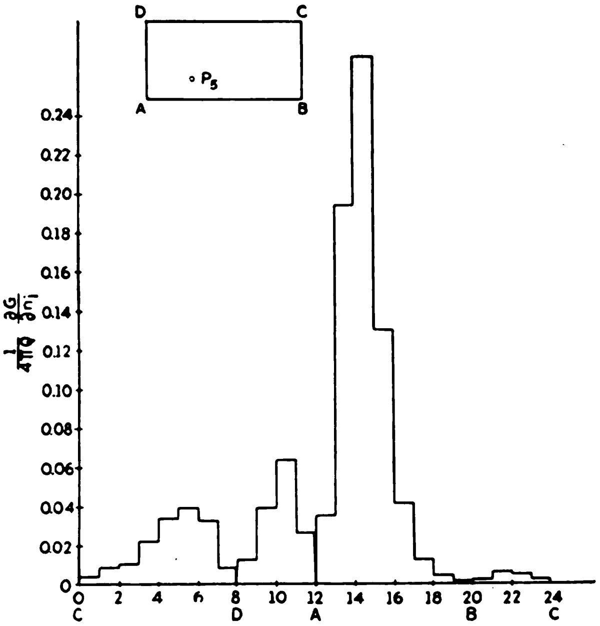

Fig. 17. Chart of Measured Charge for Point P_5 (24, 10)

Substituting $U=(G-2\log r), \nabla^2 U=0$, and $\nabla^2 V=0$ in Equation (14) the double integral vanishes; and after transposing adequately the line integral, it becomes:

$$\int_S \left(G \frac{\partial V}{\partial n_i} - V\frac{\partial G}{\partial n_i}\right) ds = 2\int_S \left(\log r \frac{\partial V}{\partial n_i} - V \frac{\partial \log r}{\partial n_i}\right) ds \qquad (15)$$

Since according to Condition (2) the integrated function $(G-2 \log r)$ is harmonic inside the whole region, the line integral relates to the boundary. We get the value of the line integral on the right-hand side of Equation (15) by substituting $\nabla^2 U=0$ and $U=\log r$ in Equation (14):

$$\int \left(\log r \frac{\partial V}{\partial n_i} - V \frac{\partial \log r}{\partial n_i}\right) ds = -\int\int \log r \, \nabla^2 V \, d\tau \qquad (16)$$

With regard to log r in the integrand in the double integral, the latter becomes infinite at P $(r=0)$, or we say the integrand has a pole at P. Therefore we surround the point by a small circle with the radius ρ and consider now the region between this circle and the boundary. Then we take the line integral over the path, denoted by the arrows in Fig. 1; or since it cancels along the straight lines, it has to be taken over the boundary and the circle. Within the region thus formed, the double integral vanishes, because $\nabla^2 V=0$ and the integrand has no longer a pole. Along the small circle $(ds=\rho d\,\psi)$ it becomes:

$$\lim(\rho \to 0)\left\{\int_{2\pi}^{0} \frac{\partial V}{\partial n_i} \rho \log \rho \, d\psi - \int_{2\pi}^{0} V \frac{1}{\rho} \rho \, d\psi \right\}$$

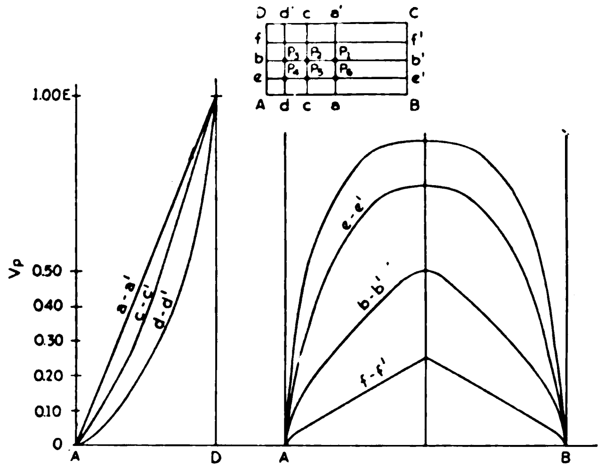

Fig. 18. Plots of Charges Appearing on Parallel Planes in a Rectangular Region When Side *AB* is Held at Constant Potential and the Other Sides are Grounded

Since $\lim\limits_{\rho\to 0} \rho \log \rho=0$ and $\frac{\partial V}{\partial n_i}$ (the electric field) is finite in the neighborhood of P, the first part vanishes; the second one is $2\pi V_P$. Equation (16) then assumes the form:

$$\int_S \left(\log r \frac{\partial V}{\partial n_i} - V\frac{\partial \log r}{\partial n_i}\right) ds + 2\pi V_P = 0$$

wherein the line integral refers to the boundary. At last with respect to the assumption that $G=0$ according to Condition (3), at the boundary Equation (15) becomes:

$$4\pi V_P = \int_S V \frac{\partial G}{\partial n_i} ds \qquad (17)$$

whereby Equation (2) is proved.

(*To be continued*)

Hot-cathode Thyratrons

PART II: OPERATION

By **Dr. ALBERT W. HULL**
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12. Summary of Characteristics

THE nature and the unique characteristics of the thyratron were described in Part I. A brief summary of these characteristics may serve as an introduction to this installment which will describe the method of operation and give a few illustrative examples.

The *thyratron* consists of a cathode, grid, anode, and a small amount of inert gas. The current passes through the tube as an arc whose starting may be controlled by the grid. After starting, it cannot be further influenced by the grid but it can be stopped by removing the anode voltage. The operation of the thyratron consists in periodically removing the anode voltage to stop the discharge, and controlling its re-starting by the grid. The tube therefore operates with an intermittent arc discharge whose *average current* is controlled by the grid. The currents which can thus be controlled are large compared with those of high-vacuum tubes under similar conditions. Hence the field of application of the thyratron is to be compared with that of relays, multiple-contact rheostats, and movable-coil reactors. For many purposes, the thyratron has advantages over these devices, *viz.*, fineness of control, absence of wear, and smallness of power required for control, combined with high power efficiency. For example, in the future, thyratrons may be used in series with d-c. motors to control the starting, stopping, and braking or deceleration without the use of rheostats or contactors. The regulation of current for starting and for speed control is accomplished by varying the phase of the grid voltage with respect to anode voltage, so that current flows for only a small fraction of each positive half cycle of anode voltage when small power is desired, and for the whole half cycle when maximum power is needed (see Section 14). For deceleration the thyratron operates as an "inverter," as described in Section 17, converting the d-c. power of the counter e. m. f. of the motors into a-c. power which is fed back into the a-c. line, thus taking energy from the motors and delivering it to the line.

On the other hand, the thyratron is capable of controlling the most delicate operations, such as the sorting of fruit according to color and size, the registration of pressures, or the measurement and control of small variations of distance. This laboratory has designed a sensitive rheostat in which a displacement of $\frac{1}{100{,}000}$ inch will start or stop a current of many amperes through the thyratron. It consists of a pile of thin carbon disks in series with a resistor and a source of a-c. voltage, the voltage across the resistor being applied to the grid of the thyratron. A slight increase in pressure in the carbon disks, requiring a motion of only $\frac{1}{100{,}000}$ inch, will decrease the resistance of the pile sufficiently to raise the voltage across the resistor by one volt, which will start the thyratron.

Fig. 23. Hot-cathode Thyratron for 100 Amp., 20,000 Volts. It consists of a metal tube, in one end of which an insulated cathode is sealed and in the other an anode. The metallic enclosing case acts as the grid. The tube is thoroughly evacuated and a drop of mercury introduced to furnish the required vapor

The *grid-control ratio* of the thyratron, which is its only characteristic constant, is defined as the ratio of negative grid voltage to positive anode voltage that will just allow current to start. This ratio is constant for tubes in which the glass walls do not exert a grid effect, and can be expressed by

$$\rho = -\left[\frac{E_g}{E_p}\right]_{i_p=0}$$

where E_g is measured with respect to the most negative electron-emitting point of the cathode, and is to be corrected for contact potential difference, if any, between the grid and cathode, and for initial velocities of the electrons. The contact potential may be as much as two volts, the initial velocities of the order one-half volt. (12) The power output does not depend upon ρ, hence the best value of ρ is the smallest that can be used, since this means that a small range of E_g values will suffice for control. If a moderate amount of control power is available, one watt or even less, ρ may preferably be 1000 or more. If the input power is small, as in the case of photo-electric input control or a high-impedance input transformer, the maximum desirable value of ρ is limited to about

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(12) For measurement of ρ it is simpler to use the equivalent definition $\rho = -\left[\frac{\Delta E_g}{\Delta E_p}\right]_{i_p=0}$, where $i_p=0$ is to be taken as the limiting value; *i.e.*, the ratio of plate and grid voltages to be observed in each case is the limiting ratio at which plate current will just start.

100 by the requirement that the grid must not catch electrons from the cathode under starting conditions. Like the amplification factor in pliotrons, ρ depends only on the dimensions and relative distances of grid and plate. It can be given any desired value by proper choice of these dimensions.

The *maximum current* that a thyratron can carry has two limitations: The first is that the current must not exceed the pure electron emission of the cathode, which is essentially the same as in vacuum.(13) This limit must be imposed by the resistance of the load in the plate circuit, because the tube has no appreciable internal resistance within its operating range. If the load resistance fails to limit the current to this value, the tube develops a pseudo-resistance in the form of a high voltage-drop at the cathode, which rapidly disintegrates the cathode. The second limitation depends upon the size and electron emissivity of the grid, and is that value of current whose passage will heat the grid to an electron-emitting temperature.

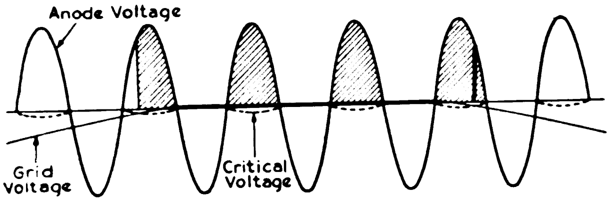

Fig. 24. Control Characteristic of a Thyratron When the Grid Voltage is Slowly Varied and the Anode Voltage is Alternating. Current (shown by the shaded area) starts in any cycle when the grid voltage becomes more positive than the critical value (dotted line) and flows for the remainder of the cycle

A fraction of a milliampere of grid emission will produce enough ions, under most circumstances, to form a sheath over the surface of the grid and modify or prevent control.

The *efficiency* of the thyratron, for anode potentials of 250 volts or more, is comparable to that of rotating machinery. Its power losses are due to the internal voltage drop and to the energy consumed in cathode excitation. These losses are much smaller than in the pliotron. The internal arc drop of the thyratron is about 12 volts for a hot-cathode thyratron utilizing mercury vapor, and is nearly independent of current. The cathode excitation may also be made very small by proper cathode construction. It may be reduced to approximately one per cent of that of a pliotron, *viz.*, to 0.6 watt per average ampere, for one-half sine wave operation at full rated output. The total loss is therefore 12.6 watts per ampere at full load, and 18 watts at one-tenth normal load. The resulting efficiency at 250 volts is 95 per cent at full load, and 92.8 per cent at one-tenth load; at 500 volts, 97.5 per cent at full load, and 96.4 at one-tenth load.

The *gas pressure* should be between 1 and 100 microns when mercury vapor is used, and somewhat higher for argon, neon, or helium. Where the highest efficiency is desired, the gas may be an alkali vapor (such as sodium or caesium) to which may be added an inert gas to assist in starting. In the case of mercury vapor, the pressure may be maintained constant by controlling the temperature of a single drop of mercury at a remote extremity of the tube.

13. General Method of Operation with Alternating Anode Voltage

The simplest method of operating a thyratron is to impress alternating voltage on the anode and any desired voltage upon the grid, as indicated in Fig. 24. The critical value of grid voltage, at which current will just start, is proportional to the instantaneous anode voltage, plus a small correction for contact potential and initial velocities. It is represented, for a typical thyratron, by the dotted curve in Fig. 24. An arbitrary voltage impressed upon the grid is represented by the curve marked "grid voltage." It is drawn as if impressed through a high resistance, which prevents appreciable positive values of grid voltage (because of electron current from cathode to grid) but does not affect negative values.

The operation is as follows:

As long as the grid voltage is more negative than the critical value, no current will flow. Whenever the grid voltage becomes less negative than the critical value, current starts and continues for the remainder of the half cycle. Its value, once it starts, is limited only by the resistance of the circuit or load. If the grid voltage varies slowly, as in Fig. 24, starting will occur between the beginning and middle of the cycle, if at all. The current will consist of pulses, from one-quarter to one-half cycle long, represented in Fig. 24 by shaded areas. The average current during any period is the sum of these areas divided by the time. It is evident that this average may be uniformly varied from full value to one-half value by increasing the negative grid voltage from zero to the point where no current flows. For smaller currents, between one-half value and zero, the average must be taken over a longer period, and is represented by the ratio of the number of cycles in which some current flows to the total number. For many purposes this long-period average is satisfactory, especially when the system to be controlled possesses large inertia.

As examples of this type of operation we may consider a method of temperature control for electric furnaces, and a method of voltage regulation of alternating-current generators. Typical circuits for these applications are illustrated in Figs. 25 and 27. Fig. 25 shows a circuit for controlling the voltage of an a-c. generator by means of a thyratron. The voltage-sensitive element is a bridge of dissimilar resistances or impedances,(14) of which one diagonal pair may be wire resistances that obey Ohm's law, but the other pair are resistances that deviate from Ohm's law in either instantaneous or average value. A simple form of such resistance is a tungsten-filament lamp,(15) whose equilibrium current varies as the square root of the voltage. Since the resistances follow different laws, it is evident that the midpoints a and b can be at the same potential for only one value of terminal voltage. This defines the *normal* voltage. At this voltage the thyratrons are so nearly balanced that they are undecided whether to start or not, and operate about half the time. Their action, when they operate, is to feed more current to the generator field than could flow from the exciter through the resistance R, thus increasing the voltage. Any deviation of generator voltage from normal unbalances the bridge, *i.e.*, produces a voltage between a and b, which is stepped up by a transformer and applied to the grids of the thyratrons. The transformer is connected in such sense that a rise of generator voltage makes the grids negative during the half cycle when the respective anodes are positive, thus preventing the thyratron from operating and decreasing the generator field current; while a fall of generator voltage below normal gives positive grid and continuous thyratron operation, thus strengthening the generator field and increasing the voltage. The absence of mechanical inertia makes this method of voltage regulation remarkably free from hunting or overshooting of voltage with sudden changes of load. The overshooting which still remains is due to the electrical inertia of the generator field, and may be reduced to any desired degree by increasing the resistance of the field circuit.(16)

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(13) Thyratrons with mercury-pool cathodes might appear to have unlimited current capacity for short periods. They have a limitation, however, as was pointed out by Langmuir, which depends upon the finite amount of gas or vapor available for producing ions to neutralize space-charge. When all the gas is ionized, a further increase in current can be obtained only by increasing the speed of the electrons which means increased voltage drop and positive internal resistance. At a mercury-vapor pressure corresponding to 20 deg. C., this limiting current is only 1.5 amp. per sq. cm.; at 30 deg. C., 8.5 amp. per sq. cm.; and at 40 deg. C. 37 amp. per sq. cm. See "Studies of Electric Discharges in Gases at Low Pressures" by Langmuir and Mott-Smith, GENERAL ELECTRIC REVIEW, 27, p. 762, Nov., 1924.

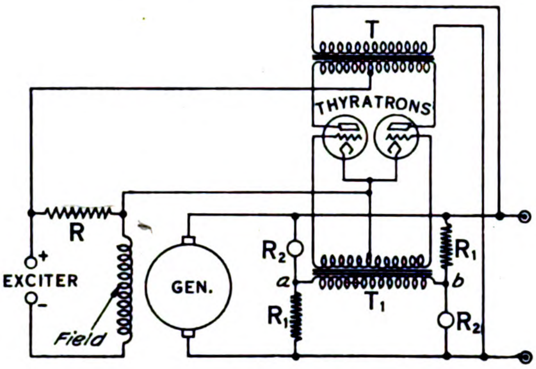

Fig. 25. Circuit for Controlling the Voltage of An A-c. Generator by Means of a Thyratron

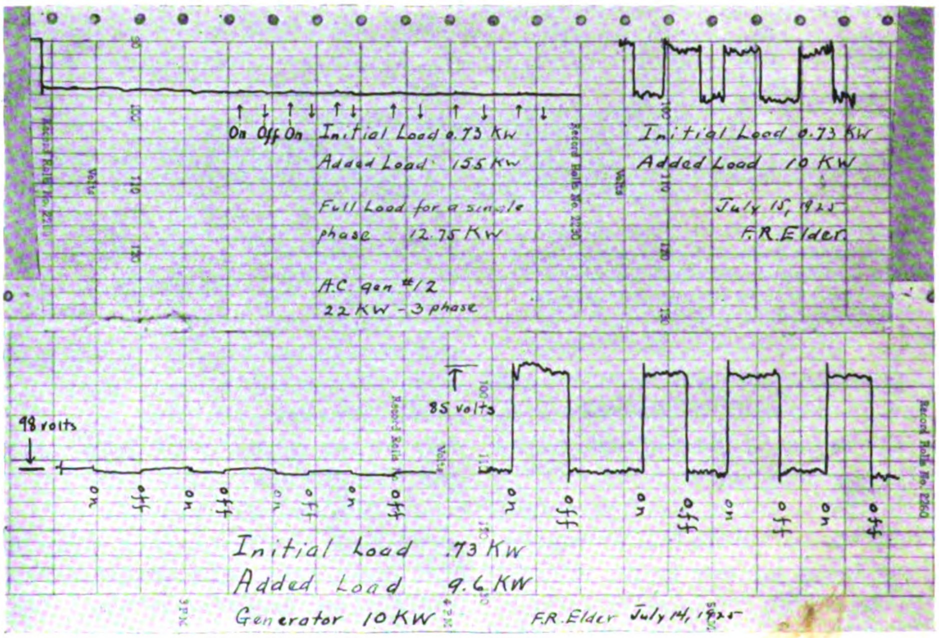

Fig. 26. Recording Voltmeter Records Showing Regulation of Two Small Alternators by a Thyratron. The left-hand portion of each record was taken with the regulator attached; the right-hand portion without regulation. Full load was thrown on and off at the points indicated

Fig. 26 gives two recording voltmeter records showing the performance of two small alternators, of 10 and 15 kw. capacity respectively, regulated in this way. The left-hand portion of each record was taken with the regulator attached; the right-hand portion without regulation. Full load was thrown on and off at the points indicated. It will be noted that the regulator holds the voltage within one-quarter of one per cent from no load to full load, and that the correcting action is so rapid that the voltmeter needle does not move when full load is thrown on. The resistances R_2 in these tests were standard Mazda C lamps, run on half rated voltage.

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(14) This arrangement is not new. A bridge of this type, consisting of carbon lamps in one pair of bridge arms and inductances in the other, was patented by Bradley in 1883 (U. S. Patent 280563) and extensively used by Edison as a voltmeter for electric light circuits.

(15) This is a pseudo non-ohmic resistance, the deviation being due to change in temperature. It has, therefore, a time-lag, which is of the order of 1/30 sec. for the smallest filament. If greater speed of action is required a true non-ohmic resistance should be used, such as a thermionic tube, with either temperature-limited emission or space charge-limited emission; a "contact" resistance, such as the "rectox" rectifier; crystal detectors of various kinds; or conductors consisting of conducting material dispersed in an insulating matrix, whose current may vary as the cube or even higher power of the voltage; or a saturated-core reactor. There are two other types of non-ohmic resistance which utilize a change in temperature and hence have a time-lag, but are about five times as sensitive as the foregoing types, *viz.*, a photo-electric tube illuminated by a lamp connected across the generator terminals, and a temperature-limited thermionic filament energized by the generator voltage.

(16) The use of *true* non-ohmic resistance, without temperature lag, is assumed in this case.

A similar test was made with a 100-kw., 3-phase alternator, regulating one phase. In this case the thyratrons operated upon the field of the exciter. The regulation was satisfactory, but the characteristic time lag between exciter and alternator voltage was evidenced by an instantaneous overshooting of the voltmeter when load was thrown on or off. It is therefore preferable to use a large thyratron operating directly upon the field of the generator.

Fig. 27 shows a method of maintaining constant temperature by means of a thyratron. The temperature-sensitive element is an a-c. Wheatstone bridge, consisting of four resistances, one of which, the so-called "resistance thermometer," is placed in the furnace whose temperature is to be controlled. Normal temperature corresponds to a balance of the bridge, *i.e.*, no a-c. voltage between the points *a* and *b*. It is adjusted to any desired value by varying the resistance of one of the fixed arms. A rise of temperature above normal unbalances the bridge, and this unbalance-voltage, after being stepped up by a transformer, is applied to the thyratron grid, in such sense as to make the grid negative during the half cycle when the anode is positive. This stops the flow of current through the thyratron and allows the relay to open and interrupt the heating current. Similarly, a temperature below normal gives an unbalance of opposite phase, causing the thyratron to operate and hold the relay closed. By this means it is easy to hold the temperature of a large furnace constant within ten degrees at 800 deg. C. The ten-degree variations are caused mainly by the lag in temperature of the thermometer and the furnace heating coils, because of their heat capacity. This lag can be minimized in many ways. One of the simplest methods, and the most accurate, is to connect the furnace winding directly in series with the thyratron, and obtain continuous modulation of the heating current by "phase control."

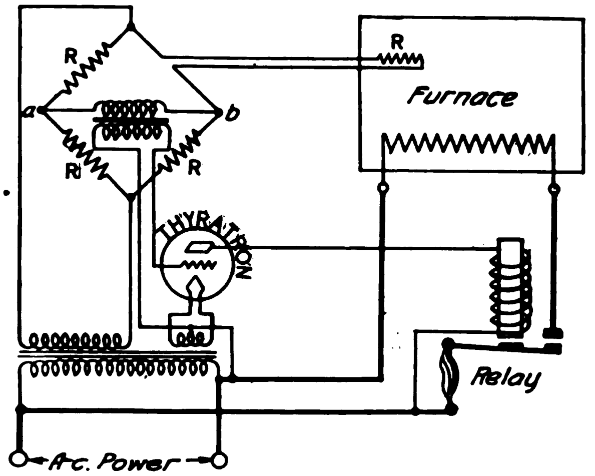

Fig. 27. Circuit for Controlling the Temperature of An Electric Furnace by Means of a Thyratron. The controlling element is an a-c. Wheatstone bridge with a resistance thermometer in one arm

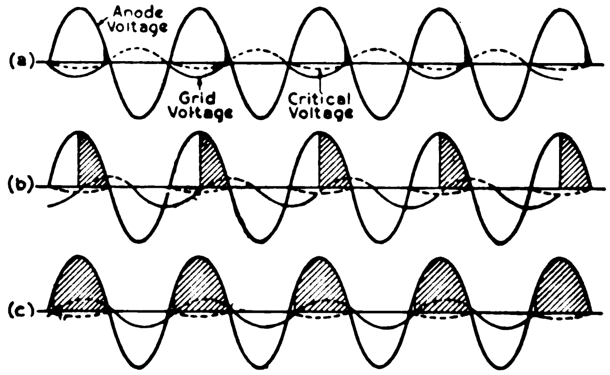

Fig. 28. Control Characteristics of a Thyratron with Alternating Anode *and Grid* Voltage. The current (shown by the shaded area) is varied by *varying the phase of the grid voltage*. In Case (*a*) the grid voltage is almost 180 deg. out of phase with the anode, so that current starts virtually at the end of each cycle; in Case (*b*) it is advanced so that current starts at the middle of the cycle; and in Case (*c*) near the beginning

14. Phase Control

A more perfect control of average current may be obtained by impressing alternating voltage upon both grid and anode, and varying the phase of the grid voltage with respect to that of the anode. With this method of operation some current flows through the thyratron in every cycle. The current starts, as in the general method described in the last section, whenever the grid voltage becomes more positive than the critical starting voltage, and when started it flows for the remainder of the half cycle. But, whereas with the slowly varying grid potential considered in the last section the time of starting could be varied only from the middle to the beginning of the half cycle, in this case, by phase control, it can be varied from the extreme end of the cycle to the beginning. Hence the current can be varied continuously from zero to full value. Fig. 28 shows three typical stages in this type of control. The amount of current per cycle in each case is represented by the shaded area. In Case (*a*) the grid voltage is nearly 180 deg. out of phase with the anode voltage, and current starts near the end of the cycle; Case (*b*) shows the grid voltage advanced in phase so that the current starts at the middle of the cycle; while in Case (*c*) the grid voltage is nearly in phase with the anode voltage and current starts at almost the beginning and flows for practically the whole of the half cycle.

The simplest method of varying the phase of the grid voltage with respect to anode voltage depends upon the well-known combination of resistance, inductance, and capacity; one of which is varied to change the phase.

Typical combinations are shown in Figs. 29 and 30. Fig. 29 shows a series combination of inductance and resistance. As the resistance is varied from infinity to zero, the alternating voltage between cathode and grid remains constant in amplitude but is progressively retarded through 180 deg. in phase, as indicated in the vector diagram. Exactly the same changes are produced by the capacity-resistance combination represented in Fig. 30, except that the direction of phase rotation is reversed. With the resistance in the right-hand arm, as shown in Fig. 30, the phase of the grid voltage is retarded by a diminution of resistance, from a value 180 deg. behind the anode voltage to 360 deg. behind.

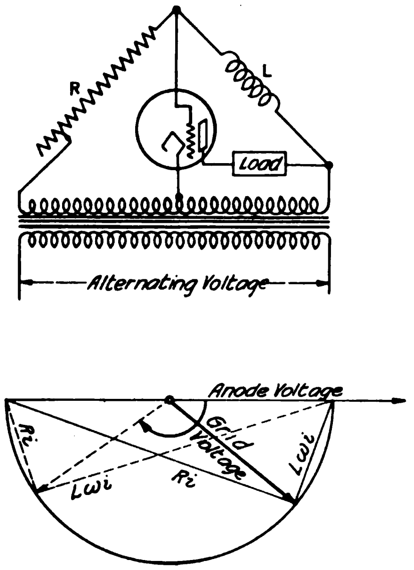

Fig. 29. Phase-shifting Circuit Consisting of an Inductance in Series with a Variable Resistance. The phase is retarded through 180 deg. as the resistance is decreased from infinity to zero

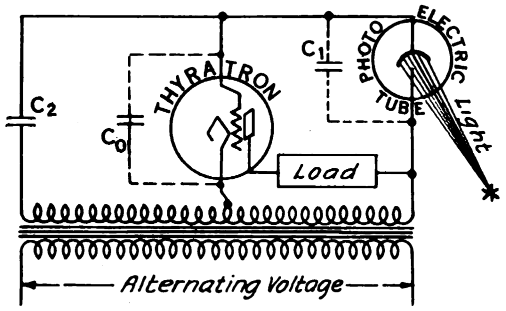

Fig. 31. Circuit for Turning on a Thyratron by Light. The current increases with increased light

The resistance *R* may be varied by a movable contact, as indicated in Fig. 30; or it may consist of a thermionic tube whose resistance can be controlled by grid voltage or filament temperature, or a photoelectric tube whose resistance depends upon illumination, or a selenium or other light-sensitive resistance. Alternatively, the resistance may remain constant and the inductance or capacity be varied to change the phase.

15. Examples of Phase Control

As examples of phase control, the problem of controlling a thyratron by photo-electric current will be considered.

A capacity-resistance circuit that is particularly well adapted to this purpose is shown in Figs. 31 and 32. Fig. 31 shows the circuit for starting the thyratron current by means of light and increasing it proportionally with increased illumination; Fig. 32 gives the corresponding circuit for turning off the thyratron current by means of light. Fig. 31 is identical electrically with Fig. 30, the photo-electric tube constituting the resistance,(17) except that there is in parallel with this resistance a small condenser C_1, consisting of the capacities between anode and grid of the thyratron and between anode and cathode of the photo-electric tube. The best value for the capacity

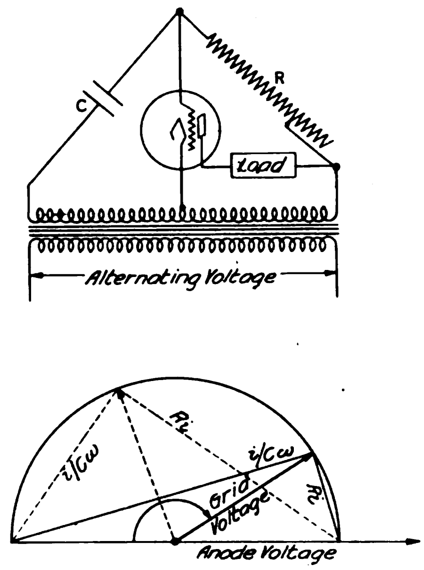

Fig. 30. Capacity-resistance Phase-shifting Circuit. The phase is retarded by decreasing resistance

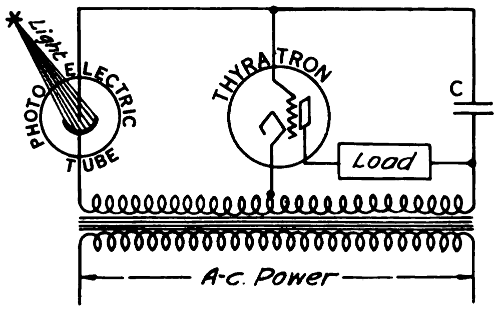

Fig. 32. Circuit for Turning Off a Thyratron by Means of Light. The current is either all on or all off

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(17) The ordinary photo-electric tube is only a half-wave or *one-way* resistance. A *two-way* photo-electric tube may be used, consisting of two similar plates, both coated with alkali metal. In the circuit in Fig. 29 this is not necessary, since, during the half cycle when the photo-electric tube is non-conducting, the grid tends to become positive, and catches electrons from the cathode, which thus constitutes its resistance during this half cycle.

In the circuit of Fig. 32, on the other hand, the grid is negative during the non-conducting half cycle and hence catches no electrons. Here a two-way photo-electric tube should be used, or some other means of "completing" the resistance.

C_2 in the other branch depends upon the type of response desired. It must in all cases be at least as large as C_1, otherwise the maximum current will flow in the thyratron at all times, even with no light. This may be clearly seen in Fig. 33, which shows the grid and plate voltage curves for an under-neutralized thyratron, case (*a*), and a slightly over-neutralized one, case (*b*), with different values of light intensity. The current starts, in each case, when the grid becomes more positive than the critical value shown by the dotted line. In the under-neutralized case, *i.e.*, C_2 less than the electrode capacities C_1, the current starts at the beginning of the cycle for all values of light intensity, including zero. In case (*b*), on the other hand, where the capacity is slightly over-neutralized ($C_2 > C_1$), there is no current when the light is zero, a small current starting almost at the end of the cycle for weak light, and more current, *i.e.*, earlier starting, the stronger the light.

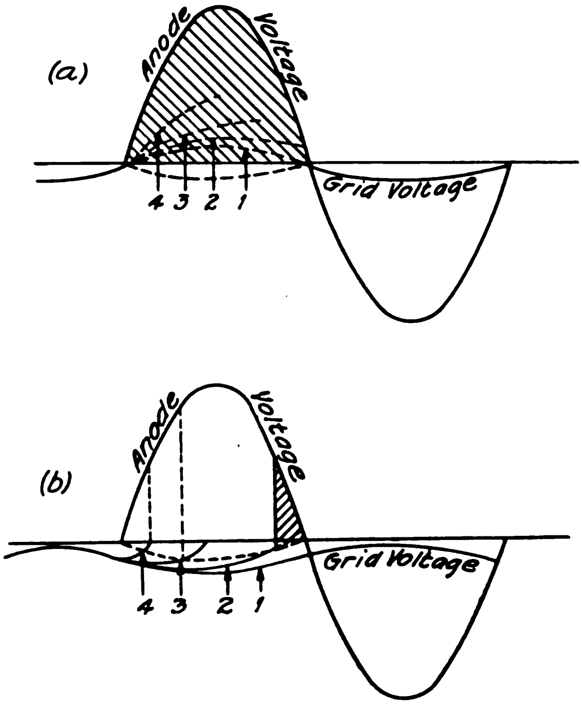

Fig. 33. Grid Voltage of an Under-neutralized Thyratron, Case (*a*), and a Slightly Over-neutralized one, Case (*b*), in the Circuit of Fig. 31. Curve *1* is the grid voltage with no light; Curves *2*, *3*, and *4* refer respectively to increasing amounts of light. Current starts, in each case, when the grid voltage becomes more positive than the critical value shown by the dotted line

TABLE I

RELATION BETWEEN ILLUMINATION AND THYRATRON CURRENT

Calculated on assumption that $C_1 = C_0 = 10\ \mu\mu$ farads and conductivity of photo-electric tube $= 10^{-7}F$, where F is the illumination in lumens

Illumination (Lumens)	THYRATRON CURRENT (FRACTION OF MAXIMUM)		
	$\frac{C_2}{C_1} = 1.1$	$\frac{C_2}{C_1} = 2$	$\frac{C_2}{C_1} = 10$
0.001	0.018	....	....
0.002	0.062	....	....
0.005	0.217	....	....
0.01	0.359	0.026	....
0.02	0.492	0.092	....
0.03	0.563	0.176	....
0.05	0.663	0.340	0.016
0.07	....	0.469	....
0.1	0.814	0.610	0.062
0.2	0.930	0.836	0.203
0.3	....	....	0.370
0.4	....	....	0.509
0.5	0.986	0.968	0.627
0.7	....	....	0.760
1.0	0.996	0.991	0.864
2.0	0.999	....	0.962
10.0	....	0.999	0.998

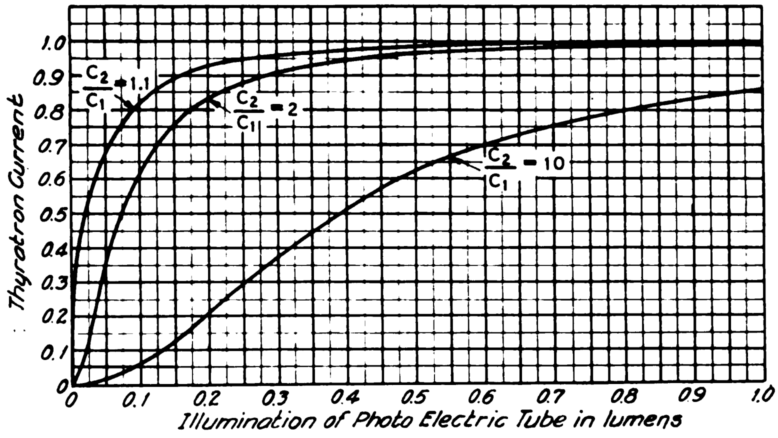

Fig. 34. Variation of Thyratron Current with Illumination of Photo-electric Tube for the Circuit Shown in Fig. 31. The currents are calculated from the phase angles, assuming the conductivity of the photo-electric tube to be $\frac{1}{r} = 10^{-7} L$ (L = illumination in lumens), and the internal capacities C_1 and C_0 to be 10 $\mu\mu$ farads each

The thyratron current is not, in general, strictly proportional to the illumination, but becomes more nearly so the larger C_2. This is shown in Table I and Fig. 34, which give the average thyratron current as a function of illumination, for three different ratios of $\frac{C_2}{C_1}$. The values given are calculated,(18) assuming

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(15) The phase angle between grid and anode voltage is

$$\alpha = \tan^{-1} \frac{r\,\omega\,(2\,C_2 + C_0)}{1 + r^2\,\omega^2\,(C_1 - C_2)\,(C_0 + C_1 + C_2)}$$

and the integral current per cycle is

$$\int_{\pi - \alpha}^{\pi} \sin\ \alpha\ dx = 1 - \cos\ \alpha$$

$C_1 = C_0 = 10\ \mu\ \mu$ farad, and assuming a gas-filled photo-electric tube operated far below critical voltage, so as to have an approximately linear volt-ampere characteristic and a sensitivity of 10 microamperes per lumen at 100 volts. This is rather low sensitivity which is attainable in a very stable type of photo-electric tube.

It will be noted that the sensitivity for small amounts of light is greater when C_2 is only slightly greater than C_1 (this is also evident from Fig. 33), while the proportionality between light and current is better when C_2 is large compared with C_1.

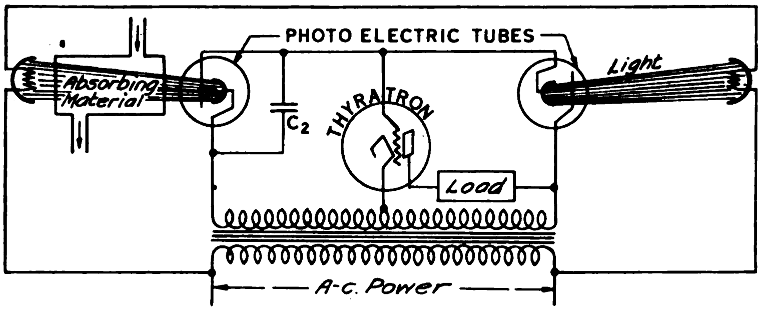

Fig. 35. Balanced Photo-electric Circuit for Controlling a Thyratron. The illumination of each cell is 1000 times that necessary to start or stop the thyratron (cf. Fig. 34). Hence the introduction in either light-path of any substance that absorbs or obstructs one-tenth of one per cent of the light, will change the thyratron current from zero to full value or vice versa

The circuit shown in Fig. 32 is adapted to *turning off* current by means of light. It does not, however, like the circuit of Fig. 31, give a continuous variation of current with increasing light, but a discontinuous jump from full current to zero. The current is constant at maximum value up to a certain critical light intensity, and is zero for all intensities above this. This is true for all values of capacity ratio $\frac{C_2}{C_1}$ that will allow current to flow at all. The reason that the current cannot be gradually decreased is that the phase rotation of the grid is in the wrong direction, *viz.*, a progressive *advance* with increasing illumination, as can be seen by comparison of Fig. 32 with the vector diagram of Fig. 30. It may be seen more clearly, perhaps, in the plot of grid voltage with different amounts of light, shown in Fig. 36.

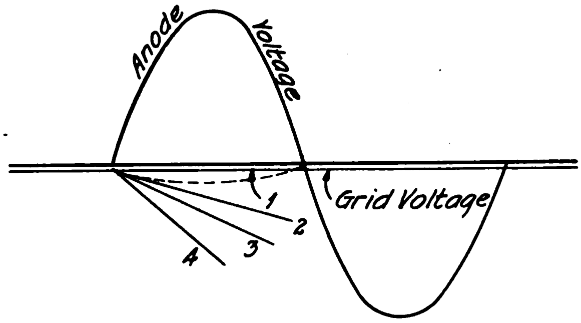

Fig. 36. Grid Voltage *vs.* Time for the Ciruict Shown in Fig. 32. Curve *1* is for no light; Curve *2* for weak light; Curve *4* for strong light. Note that the thyratron starts at the beginning of the cycle, if at all

This circuit therefore provides a sensitive on-or-off light relay, which can be operated by a very small amount of light.

It may be employed, for example, to operate a relay to control electric beacons or lights in public buildings, turning them off when daylight reaches a desired level and turning them on again whenever the daylight falls below this level. It is to be noted that only a-c. power is required, and that the circuit element which determines the light level at which the thyratron will start is a condenser, C_2, which is more constant and reliable than the high resistances usually employed with photo-electric tubes.

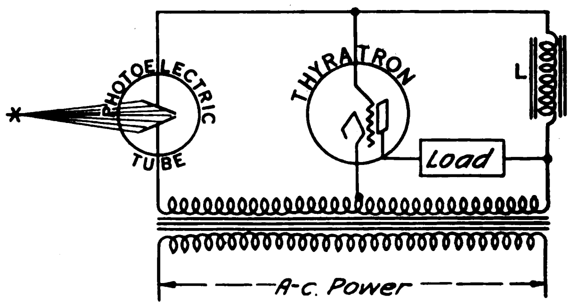

Fig. 37. Circuit for *Progressively* Turning Off the Current in a Thyratron with Increasing Illumination of a Photo-electric Tube (cf. Fig. 31)

Instead of balancing the photo-electric current against a condenser charge, as in Fig. 32, it may be balanced by an equal photo-electric current in another photo-electric tube, as shown in Fig. 35. The two photo-electric tubes are illuminated by similar lamps operated in series or parallel from the same voltage source, so that variations in voltage affect the two tubes equally. With 21-c.p. lamps focussed one on each tube, as in Fig. 33, it may be seen from Fig. 32 that the light falling on either tube is 1000 times as much as is required to operate the thyratron. Hence, with the illuminations adjusted to equality, a change of one-tenth of one per cent in one of them will start the thyratron. This change may be produced by the interposition of a small amount of absorbing or scattering material, such as smoke, in the path of the light to one of the cells. In the case of smoke, the thyratron can then be made to operate suitable equipment to correct the combustion conditions in the furnace.

Or, the same electrical set-up of photo-electric cells and thyratron can be employed to check the transparency of a liquid, such as oil. In this case, the liquid is in a glass cell or tube interposed in one of the light paths, as shown in Fig. 35, and a slight change in its transparency will cause the thyratron to operate indicating or control apparatus.

Still another variation consists in reducing to average daylight intensity the illumination on each photo-electric tube, and then removing one of the lamps and using daylight in its stead. This arrangement gives an even more accurate control than that described in the preceding paragraph, when electric lights are to be turned on and off or other functions are to be performed in accordance with daylight.

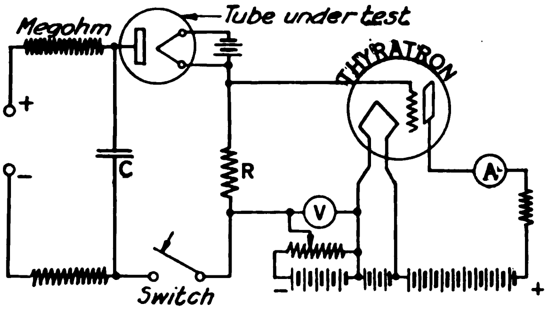

Fig. 38. Circuit for Measuring the Maximum Value of a Transient Current. The impulsive voltage *IR* across the resistance is equal to the maximum negative grid bias *V* at which the thyratron can be started by the transient impulse. The plate circuit must be opened after each measurement to stop the current and thus *re-set* the thyratron

The appropriate circuit for *progressively turning off* the current of a thyratron with increasing illumination is shown in Fig. 37. It contains an inductance, instead of capacity, in the positive branch, so that the phase rotation is in the right direction for decreasing the thyratron current with increasing illumination. The phase diagram is that shown in Fig. 29, except for small inter-electrode capacities in parallel with the resistance and inductance. The sensitiveness of this circuit, using a photo-electric tube, is less than that of the circuits in Figs. 31 and 32, for practical values of impedance, since the maximum practical inductive impedance at 60 cycles is of the order of one megohm, as compared with 100 megohms for the condenser impedance in Figs. 31 and 32. This means that approximately 100 times as much light is needed to obtain the desired phase shift. On the other hand, if the photo-electric tube is replaced by a selenium cell, whose esistance in the dark is of the same order of magnitrue as the impedance of practical inductances, the sensitiveness is equal to that of the circuit shown in Fig. 31.

16. Method of Control With D-C. Power Supply

When thyratrons are operated from a direct-current power supply, the current, once started, will continue to flow forever unless the power supply is interrupted. The thyratron under these conditions has a memory, and is adapted to record electrical events or any events that can be rendered electrical. It may be relied upon, provided the power supply is continuous, to keep its informative light burning until the operator notices it. For example, it may be used to register whether the current or voltage during a switching operation or a thunderstorm exceeds an anticipated maximum value. The anticipated value, or an appropriate fraction thereof, is applied as a negative bias to the grid. If the voltage to be recorded, whether transient or steady, exceeds this bias, it makes the grid positive and starts the thyratron, which then continues to "go" until the anode circuit is opened. Fig. 38 shows such a circuit, adapted to measure the maximum value of a transient current, that has been used by Dr. Katherine Blodgett in her investigations of thermionic emission in gases. In these tests it was necessary to use currents of very short duration, obtained by a condenser discharge, in order that the filament temperature might not be affected. The maximum negative grid bias was found at which the thyratron would start when the condenser was discharged through the tube under test and the resistance *R*. This bias voltage *V*, minus the voltage V_0 at which the thyratron starts without the discharge, equals the maximum *IR* drop: $V - V_0 = Ri_{max}$. The currents and voltages measured in these investigations were too small to register on a cathode-ray oscillograph.

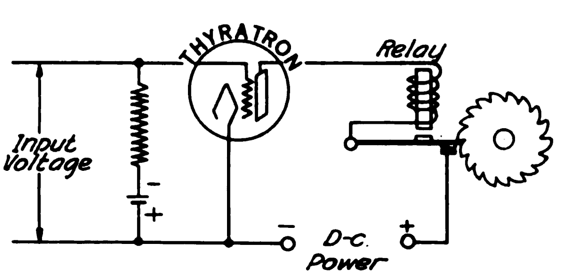

Fig. 39. Circuit for Registering Voltage Impulses by Means of a Thyratron. Each impulse, applied to the grid, starts the thyratron current. This current operates the relay, removing the anode voltage for an instant, thus automatically *re-setting* the thyratron

If repeated operation of the thyratron is desired, means must be provided for opening the anode circuit. It need remain open only for an instant, sufficient to allow the ions to diffuse away from the grid. The time required for this "de-ionization" is of the order of 10 to 100 microseconds for currents of a few amperes, and increases with current (see Section 10). A simple method of opening the anode circuit is to insert a relay in it, as in Fig. 39. so that the anode current interrupts itself. The relay opens once and closes without chatter for each event, and may be made to operate a counter as indicated in Fig. 39, while the input voltage might be produced by a beam of light interrupted, on its way to a photoelectric tube, by the passage of an automobile.

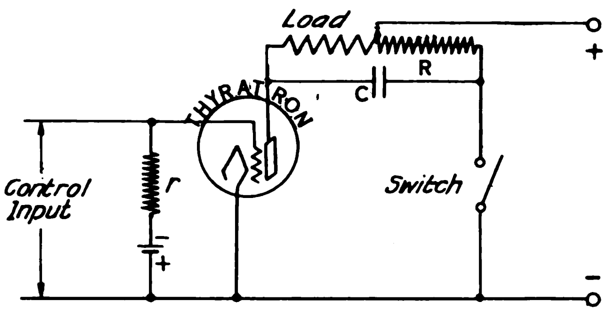

Fig. 40. General Method of Stopping the Current in a *D-c.-operated* Thyratron. The anode is made negative for an instant by closing the switch. During this instant the ions diffuse away from the grid, thus restoring grid control

An alternative and more generally applicable method of interrupting the anode current is shown in Fig. 40. A condenser C is connected, in series with a resistance R, between the anode and the positive voltage terminal. This condenser becomes charged, when current is flowing, to the potential difference across the load, which is equal to the supply voltage minus the tube drop. Assuming a supply voltage of 250 and a tube drop of 15 volts, the condenser voltage will be 235. Closing the switch will bring the potential of the right-hand condenser terminal in Fig. 40 to zero, a fall of 235 volts. The left-hand terminal, which is connected to the anode, must suffer instantaneously an equal fall, on account of the high transient impedance of the load compared to that of the condenser. This brings the anode potential to −220 volts, *i.e.*, 220 volts negative with respect to the cathode, which stops the flow of electrons and the production of ions. If there is time enough for the ions that are present to diffuse to the walls before the anode voltge again reaches +15, the grid will be in condition to again control the starting.

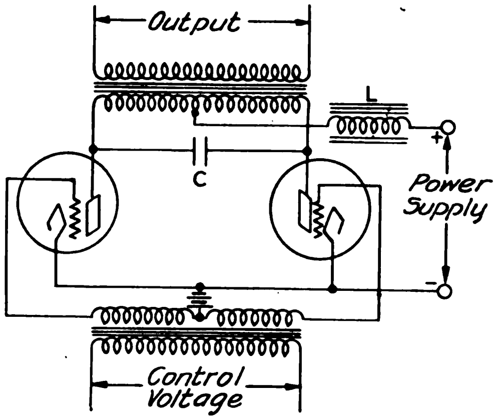

Fig. 42. "Inverter" Circuit, for Changing Direct Current to Alternating Current. This circuit is equivalent to that of Fig. 41, except for the substitution of an output transformer in place of the resistance. Control voltage for the grids, of the desired frequency, is supplied from another source

Instead of using a switch to ground the right-hand condenser terminal (Fig. 40), a second thyratron may be used, as in Fig. 41. Making the grid of this thyratron positive is equivalent to closing the switch in Fig. 40, except that the potential falls to +15 volts instead of zero, making the maximum negative anode potential of thyratron No. 1 205 volts instead of 220.(19) In this way the current is transferred from thyratron No. 1 to thyratron No. 2. It may be transferred back again by making the grid of thyratron No. 1 positive. This process may be repeated as frequently as desired, subject to the condition that the anodes shall remain negative long enough at each transfer for the ions to diffuse out of the space around the grids.

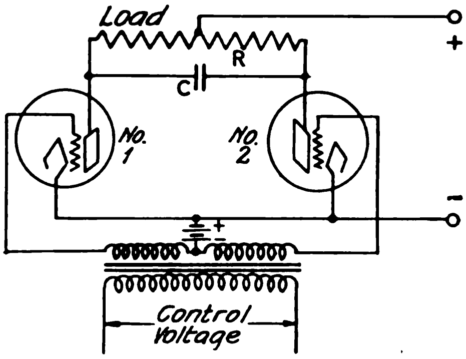

Fig. 41. Method of Stopping the Current in a D-c.-operated Thyratron by Means of Another Thyratron. Starting the second thyratron is equivalent to closing the switch in Fig. 40

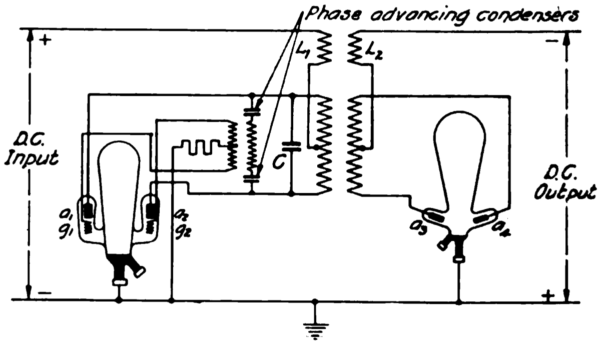

Fig. 43. Direct-current Transformer, Consisting of a Self-controlled "Parallel-type" Inverter, Transformer, and Rectifier

17. Examples of D-C. Operation—The Inverter

The circuit shown in Fig. 41 is adapted to change direct current into alternating current. It is only necessary to provide an output circuit by substituting for the resistance R the primary winding of a transformer whose secondary goes to the a-c. load, as shown in Fig. 42. A choke coil L in series with the d-c. supply tends to keep the alternating current out of the d-c. line.

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(19) It is assumed that the "impedance" of thyratron No. 2 is low compared with that of the load, so that the short-circuiting of the condenser terminal is essentially instantaneous.

If the a-c. output is again rectified, after voltage step-up or step-down as desired, forming a "d-c. transformer," then it is possible to make the a-c. waves square by coupling the output to the input, and thus avoid any feedback of alternating current to the d-c. power system. This method, which is due to D. C. Prince of this laboratory, has been described in a recent issue of this magazine(20) Fig. 43, taken from Prince's article, shows the circuit and also shows the method of obtaining the grid excitation from the a-c. output.

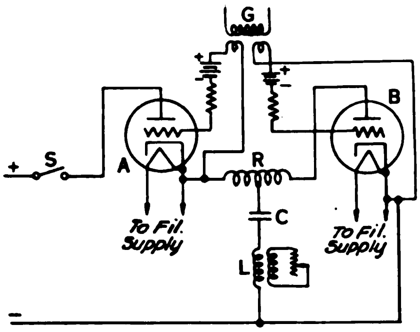

Fig. 44. Series-type Inverter, Adapted to be Driven by Control Voltage from a Separate Source

As a final example, typical circuits of a "series type" inverter, which has been investigated by A. S. Fitzgerald and M. L. Henderson of the Radio Dept., and by C. A. Sabbah of the General Eng. Dept., are shown in Figs. 44 and 45. Fig. 44 shows a "driven" type of inverter, adapted to be driven at any desired frequency by alternating current applied to the grids. Its operation is described by Fitzgerald and Henderson as follows:

"The thyratron tubes which are used have the distinguishing characteristic that no plate current will flow until the grid potential is made positive with respect to the filament, but that after plate current has once started the grid potential has no further influence. When the current is brought to zero by some external agency it cannot restart until the grid is again made positive.

"With this in mind the operation of the inverter is explained as follows. Referring to the circuit diagram it is seen that transformer G excites the grids of the two tubes so that one is positive when the other is negative. Bias batteries keep the grids normally negative.

"With the grids thus excited let switch S be closed, connecting the plate of tube A to the d-c. line. As soon as the grid of tube A becomes positive, current flows through tube A, half of reactor R, condenser C, and load transformer L. Tube B carries no current as its grid is negative. As soon as the condenser is completely charged the current stops.

"At the beginning of the next half cycle of excitation, the grid of tube B becomes positive and that of A negative. Current then flows out of the charged condenser, through reactor R, tube B and load transformer L. This current stops when the discharging action of the condenser is completed. At the beginning of the next cycle of excitation the grid of tube A becomes positive and that of B becomes negative; tube A takes current from the line and the above operation repeats at the frequency of the grid excitation.

"The function of the reactor R is to provide inductive coupling between the two tube circuits. Then if the natural action of the circuit has not reduced the current in one tube to zero within a half cycle, the starting of the current in the other tube produces a counter-voltage in the first circuit sufficient to bring the first current suddenly to zero.

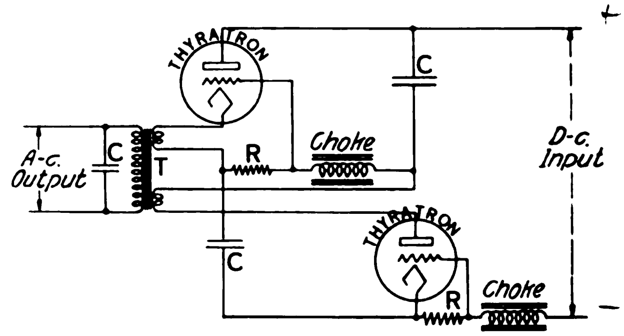

Fig. 45. Self-controlled Series-type Inverter. The frequency is determined by the characteristics of the grid transformer

"The current through the condenser and load transformer primary is alternating, so that the secondary winding can supply a-c. power to a load. By proper design of the circuit for a given frequency, this output current may be made practically sinusoidal."

Fig. 45 shows a self-oscillating inverter circuit of the series type, due to C. A. Sabbah, in which the grid excitation is derived from the output. This circuit starts generating as soon as the d-c. switch is closed, and operates at a frequency determined by the characteristics of the grid transformer. Its operation is similar to that of the circuit shown in Fig. 44.

These inverters are very stable in operation, and their efficiency is not materially different from that of rotating machinery. They have the advantages of quiet operation, absence of wear, and quick starting. Life and cost can only be estimated at present, but it is believed that they will compare favorably with those of rotating machines.

(Concluded)

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("Developed for a series of lectures for the operating and constructing engineer of mature years who desires a complete course on refrigerating engineering, but requires it to be arranged in definite learning order so that he can master the fundamental ideas before he is confronted with the heavier mathematical discussions involving thermodynamic equations." Also intended for junior and senior college students. After two short introductory chapters on definitions and on food preservation, the author continues with a discussion of the various refrigerating media, reserving separate later chapters for the more important ones such as ammonia, carbon dioxide and sulphur dioxide. The various refrigeration systems are discussed, special chapters being devoted to electric refrigeration, absorption refrigeration and the absorption machine, special absorption units, and the like. Compression systems, condensers, heat transfer and insulation, ice making, and the testing of refrigeration apparatus are also given attention. A chapter on constants and calculations, and one on thermodynamic equations provide some of the necessary theoretical material, while numerous tables and graphs throughout the text, and a set of steam and other tables, furnish certain data essential to calculations.)

Handwörterbuch des Elektrischen Fernmeldewesens. Ernst Feyerabend and others (Editors.) 2 vols., 1929, Berlin, Julius Springer.

(An extensive and up-to-date encyclopedic dictionary, in German, on the subject of electrical communication in all its phases. The subject matter of these two substantial volumes is arranged in alphabetical or dictionary style. The enecyclopedic matter has been contributed by a long list of eminent German engineers and scientists, and the resulting material molded into a harmonious whole by four editors: Dr. Ernst Feyerabend, Dr. Hugo Heidecker, Prof. Franz Breisig and August Kruckow. With its total of 1733 pages, 6000 individual entries, and its 2769 illustrations, the work covers very satisfactorily the general principles of the physics underlying electrical communication, the fundamentals of theoretical electricity, the electric circuit and various circuit diagrams, telephony, telegraphy, and radio in all its ramifications. Industrial and economic questions are also considered, numerous entries treating such subjects as interstate relations, historical development, rates and rate regulations, laws, statistics, and organization and management of communication projects in general. The work is also useful as a German-English-French technical dictionary of electrical communication terms, as the English and French equivalents immediately follow the German word or phrase. Another valuable feature is the inclusion of bibliographic references at the ends of many of the entries. This work of reference brings together a wealth of information hitherto scattered through the pages of various technical periodicals or otherwise virtually inaccessible. The typography and mechanical features are excellent. In those instances where the German-language feature is no obstacle the set should make a strong appeal to engineers and others interested in telephone, telegraph or radio work. It will no doubt find its rightful place as a reference work in many libraries, both public and private.)

Introduction to the Theory of Eddy-Current Heating. C. R. Burch and N. Ryland Davis. 72 pp., 1928, Lond., Ernest Benn, Ltd.

Manufacturing. Malcolm Keir. 611 pp., 1928, N. Y., Ronald Press Co.

Manufacturing Costs and Accounts. A. Hamilton Church. 516 pp., 1929, N. Y., McGraw-Hill Book Co., Inc.

Modern Foundry Operation and Equipment. William Rawlinson. 312 pp., 1928, Lond., Chapman & Hall.

Principles of Electric Power Transmission by Alternating Currents. H. Waddicor. 399 pp., 1928, N. Y., John Wiley & Sons, Inc.

(The nature of this work is very well expressed in the author's words when he says: "It is not claimed that anything novel is presented herein, but rather that the work is a systematic exposition of the principles underlying the electrical design of transmission lines, and contains in a complete and concise form results hitherto recorded in a very scattered literature. In the treatment of the subject familiarity with the use of complex quantities is presupposed, as a general course in alternating currents can hardly be considered complete without a discussion of this method of calculation." The main broad topics discussed are: inductance and capacitance of conductors, performance of short and of long transmission lines, conductors, and their supports, insulation and corona of overhead lines, voltage control by phase modifiers, underground cables, economics of transmission lines, over-currents and over-voltages and protection against them. Many numerical examples are solved to clarify the subject, and numerous reference figures throughout the text apply to the brief bibliographic lists appended to the chapters. An index of more than ordinary completeness is a useful feature.)

Principles of Transportation. Emory R. Johnson and others. 815 pp., 1928, N. Y., D. Appleton & Co.

Radio Manual. George E. Sterling. 666 pp., 1928, N. Y., D. Van Nostrand Co., Inc.

("For radio engineers, inspectors, students, operators and radio fans. . . . Prepared as a guide and text book to those who expect to enter the radio profession as an engineer, inspector, commercial or amateur operator. Sufficient subjects have been included whereby one may by diligent study qualify to pass the technical examinations required to secure a commercial, broadcast, or amateur operator's license." An attempt has been made, by the inclusion of chapters on the elements of electricity and magnetism, to make the volume understandable to those with no previous knowledge of electrical subjects. "Radio Communication Laws of the United States and those of the International Radiotelegraphic Convention are contained within this volume. Regulations governing the issuance and renewal of operator's licenses are included, and other information as issued by the Federal Radio Commission pertaining to the operation of various classes of radio stations in the United States." The subjects covered are, briefly: theory and application of vacuum tubes, vacuum tube circuits, modulation for broadcasting, instruments, marine vacuum tube transmitters, broadcasting equipment, arc and spark transmitters, commercial receiving apparatus, radio beacons and direction-finders, short-wave apparatus, and the handling of radio communication traffic. An ample index is provided.)

Recovery and Use of Industrial and Other Wastes. John B. C. Kershaw. 212 pp., 1928, Lind., Ernest Benn, Ltd.

Stage Lighting. Theodore Fuchs. 500 pp., 1929, Bost. Little, Brown & Co.

Steam, Air, and Gas Power. William H. Severns and Howard E. Degler. 425 pp., 1929, N. Y., John Wiley & Sons.

Steam Turbines. Ed. 6. James A. Moyer. 557 pp., 1929, N. Y., John Wiley & Sons.

The Radio Industry; the Story of Its Development. 330 pp., 1928, Chic., A. W. Shaw Co.

Treatise on the Analytic Geometry of Three Dimensions. Vol. 1. Ed. 7. George Salmon. 470 pp., 1928, N. Y., Longmans, Green & Co.

Verhandlungen des Ausschusses für Einheiten und Formelgrössen in den Jahren 1907 bis 1927. J. Wallot (Editor). 48 pp., 1928, Berlin, Julius Springer.

(A German pamphlet presenting, in new and revised form, the decisions formulated by a German committee for the standardization of scientific and technical units, symbols and terminology. The committee represents nineteen societies in Germany having an interest in such standards. The record of their work should be of value to those concerned with the technical standardization work of foreign countries.)

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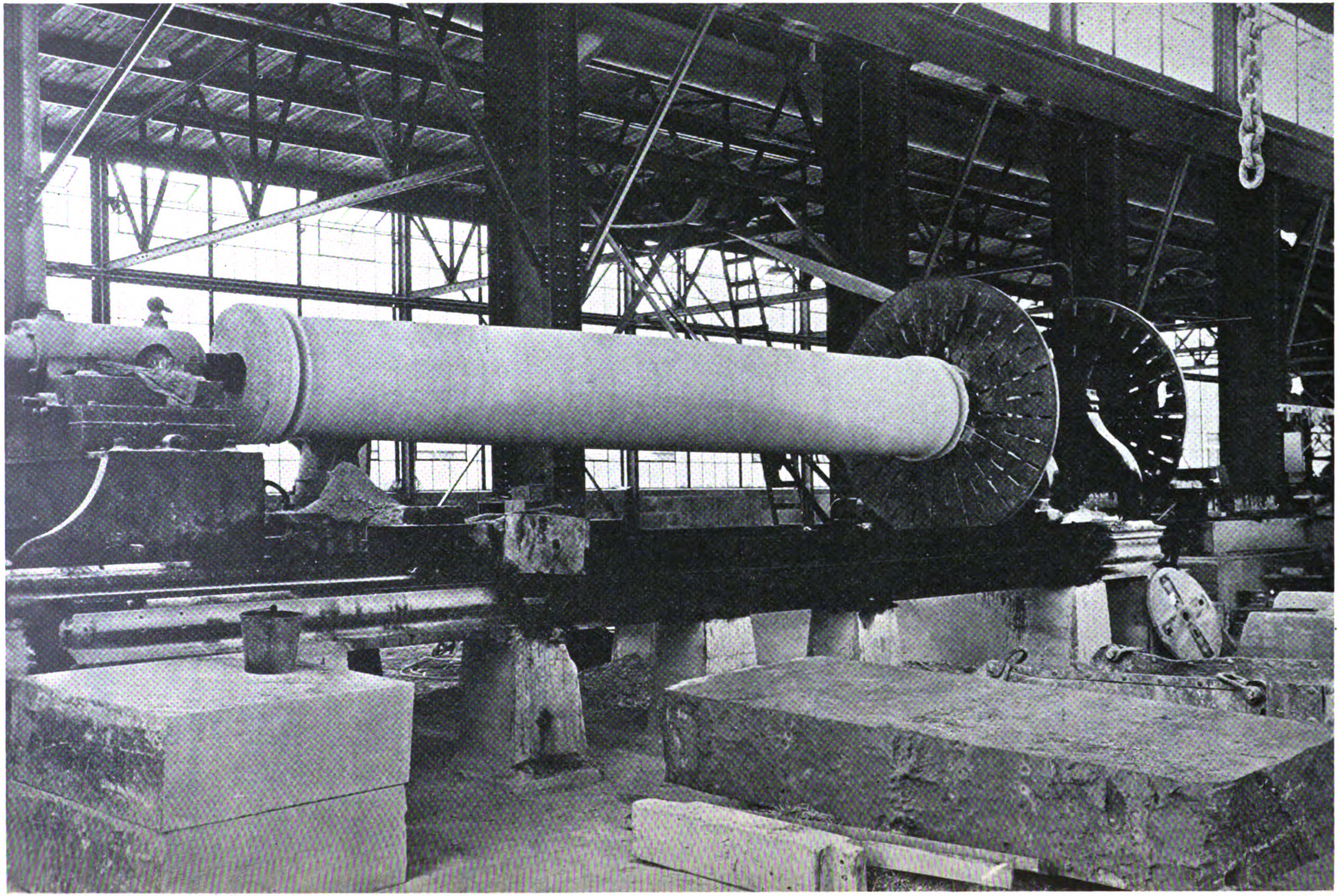


A MONOLITHIC COLUMN IN A LATHE

Consider the stonecutters in the shop—they toil not neither do they sweat, and yet no ancient ever made a shaft as true as this

GENERAL ELECTRIC REVIEW

Vol. 32 August, 1929 No. 8

THE ATMOSPHERE

We understand that many of our readers have recently bought airplanes of their own. Among these is Mr. A. R. Stevenson, who for his own education compiled a short article on the "Interpretation of Weather Maps." We publish this article as a sort of "first lesson" for the benefit of our readers who are taking up this latest and best of sports. It was reading this article that made us realize anew how complex a subject weather prediction is, on account of the many factors involved. But, however much we study this subject there must ever remain the unknown and unknowable.

We are living on our small island home, which is also our prison, and which is speeding along the invisible roads of heaven, on its eternal journeys around the sun, at the tremendous speed of more than one and a half million miles per day. A speed greater than 66,000 miles an hour! But our earth also rotates on its own axis once in 24 hours, which gives a place on the equator an additional speed of 25,000 miles a day or considerably more than 1000 miles each hour. Even at Greenwich where the diameter of the circle is so much smaller the velocity of rotation is 11 miles per minute. At the poles of the earth this velocity of rotation is nil.

If we wish to arrive at a complete figure for the velocity and complex movement of the earth we should have to add some six other movements of various magnitudes and complexities, and we should then find the speed beyond our imagination.

But although our little planet is being hurried through space at this incredible speed, when to us it appears motionless, it carries along with it not only its tremendous oceans of water, but also a vast sea of atmosphere which surrounds its entire surface—not in chaos but in cosmos, for the simple reason that the whole is ever obedient to that most mysterious of laws—universal gravitation.

Many people live their lives without appreciating the reality of the atmosphere. The earth and the waters on the earth are obviously "something," but it is harder for some to comprehend the air as something tangible and real. And yet it is this thin mantle of atmosphere that gives life to every living thing on the earth, in the waters, and in the air. It is, indeed, an ethereal sea spreading over land and ocean alike, washing every mountain and valley, nourishing the smallest flower and the mightiest tree; it is this life-giving fluid that man inhales with his first breath and surrenders with his last. But, perhaps we are using more the language of poetry than of science in calling our atmosphere an "ethereal sea," as, although we are so wonderfully made that we are unconscious of its weight, the atmosphere bears down upon us, and the surfaces of the earth, with a pressure exceeding 14 pounds on each square inch of surface, which is an equivalent pressure to a layer of water some 33 feet deep.

The exact depth of the atmosphere has not yet been determined, but unmanned, registering balloons have reached a depth (or shall we say height?) of 22 miles. The upper layers have yet to be explored before they reveal their secrets. In spite of our incomplete knowledge it is interesting to note that, in our latitude, a point is reached some seven miles above sea level where the temperature no longer decreases with height.

The atmosphere below this level is known as the "Troposphere" and above this it is called the "Stratosphere."

There is no material change in temperature with height in the stratosphere as far as man has yet explored. But it should be mentioned here that there are certain scientific considerations which would lead one to believe that at heights yet unattained there may be a marked increase in the temperature of the outer layers of the earth's atmosphere. Chief among these considerations is the large amount of absorption of the sun's rays from both ends of the spectrum which it seems must take place in these regions.

The dividing line between the troposphere and stratosphere is not at the same height above the earth all around the world. In our latitude it is about 7 miles above sea level. At the equator it is about 10 miles, and at the poles about 5 miles. This difference leads to a paradox which influences our weather conditions greatly. As although the surface air at the equator is very much warmer than at the poles, the temperature ten miles above the equator is much lower than the temperature 10 miles above the poles. Ten miles above the equator, on the Fahrenheit scale, the temperature is 110 deg. below zero, whereas ten miles above the poles the temperature is only 60 deg. below zero.

Until quite recently all man's adventures in the air were confined to the troposphere, but now both manned balloons and heavier-than-air machines have penetrated for a considerable distance into the domains of the stratosphere.

Many of the most spectacular wonders of the sky occur in the stratosphere. The beautiful auroral arcs are confined to its upper limits and those awe-inspiring and magnificent auroral draperies are apparently limited to a region extending some miles above the troposphere to about 150 miles above the earth. Shooting stars are a phenomenon of the lower half of the stratosphere, and the limit of twilight occurs about 50 miles above sea level.

The greatest depth that man has measured in the oceans of water that cover part of the earth is 32,079 feet and the uppermost limit to which the earth's surface penetrates our ocean of atmosphere is 29,002 feet. So it will be seen that even the crest of Mount Everest lies well within the limits of the troposhpere. All clouds, even the highest cirrus cloud banners decorating the pinnacles of the Himalayas, all our storms and all changes in weather, are confined to the limits of the troposphere.

Weather, or rather changes in weather, may well be defined as turbulence in the atmosphere, or more specifically turbulence in the troposphere. The greater the turbulence, the greater the change.

Now that aviation has reached a stage of national and international commercial importance and is also fast developing into a domestic luxury (which always precedes the stage of necessity), as well as being the king of sports, both the foretelling of weather conditions, and the interpretation of weather maps are of major importance.

Meterolgy had a great significance before the advent of flying. Navigators, farmers, and holiday makers were all interested; but now that man has claimed the air as well as the earth's surface for his domain, meteorology has taken on a new significance.

In one sense meteorology is an old science because our ancient shepherds, husbandmen, and (shall we say) "fakers," were all weather wise in their day and generation. But theirs was weather "lore" rather than weather science. For those interested in this old lore—and it is interesting—we recommend "Weather Lore" by Richard Inwards. But for those interested in meteorology, the new science, the literature is so extensive that none but the serious student will care to peruse it. Humphrey's "Physics of the Air" is admirable reading, but hard, and dear old Camille Flammarion's "The Atmosphere" is both instructive and entertaining. John Tyndall's writings on the rainbow and halos and other weather phenomena will, we believe, remain classics as long as our language lasts. But for real serious study we shall have to recommend those innumerable books and pamphlets that have been more recently compiled by the meteorogical services of many far-seeing governments.

These meteorological services are a valiant effort to bring weather predictions into the realm of an exact science. There are, however, so many variable factors to be considered that the task looks insurmountable; but courage and perseverance will do much now that aviation is an established fact, and now that the lives and commerce of individuals and nations may be vitally affected by weather knowledge.

If we were to visit a modern government meteorological station we should find earnest students perpetually taking measurements of the atmosphere's temperature and pressure, the wind's velocity and direction, humidity, precipitation and evaporation, the amount of sunshine and the electrical condition of the atmosphere, as well as recording optical phenomena and turbidity.

It is from these data that our daily weather maps are compiled and it is from the constant study of these and other data that the circulation of the atmosphere is becoming better understood and our weather predictions are more accurate and reliable.

Difference in gravity, pressure, and temperature are among the chief factors to be studied in determining the direction and velocity of winds; but friction, viscosity, local heating and cooling, and the deflections caused by mountains and by the earth's rotation also have to be taken into consideration.

Winds, their intensities, and direction are especially interesting to the aviators so we give below Humphrey's classification of winds.

(*A*). Winds due chiefly to local heating—whirlwinds, cumulus convection, valley breezes, sea breezes.

(*B*). Winds due to cooling—land breezes, mountain breezes, glacier winds, bora, mistral, Norwegian fall-winds, continental winds.

(*C*). Winds due to simultaneous adjacent local heating and local cooling, thunderstorm winds.

(*D*). Winds due to widespread heating and cooling—gradient winds, monsoons, trades, antitrades, tropical cyclonic winds, extratropical cyclonic winds, anticyclonic winds.

(*E*). Forced winds, or winds caused by other winds—eddies, foehns (Chinooks), tornadoes.

However, in the final analysis, it is not the great major disturbances in the atmosphere, the trade winds, monsoons, hurricanes, tornadoes, cyclones, and typhoons that the amateur aviator needs personal knowledge of, as our modern meteorological services will advise him as to these, and usually they can be readily observed and, therefore, avoided. He does, however, require a knowledge of many little local winds which, before the advent of aviation, were considered of such small consequence that some are even unnamed.

Among these winds are air fountains, air sinks, air cataracts, cloud currents, aerial cascade, wind layers, wind gusts, wind eddies, air torrents, and air breakers. The aviator does need to learn all he can about these and we recommend as a first lesson in studying them the reading of Chapter XI of Humphrey's "Physics of the Air," in which he deals with them under the title of "Winds Adverse to Aviation."

The atmosphere is such a vast subject that it seems almost impossible to say much that is useful in so short a space. It comprises so many factors and complexities that in spite of the vast literature on the subject we sometimes feel that man has only begun his studies.

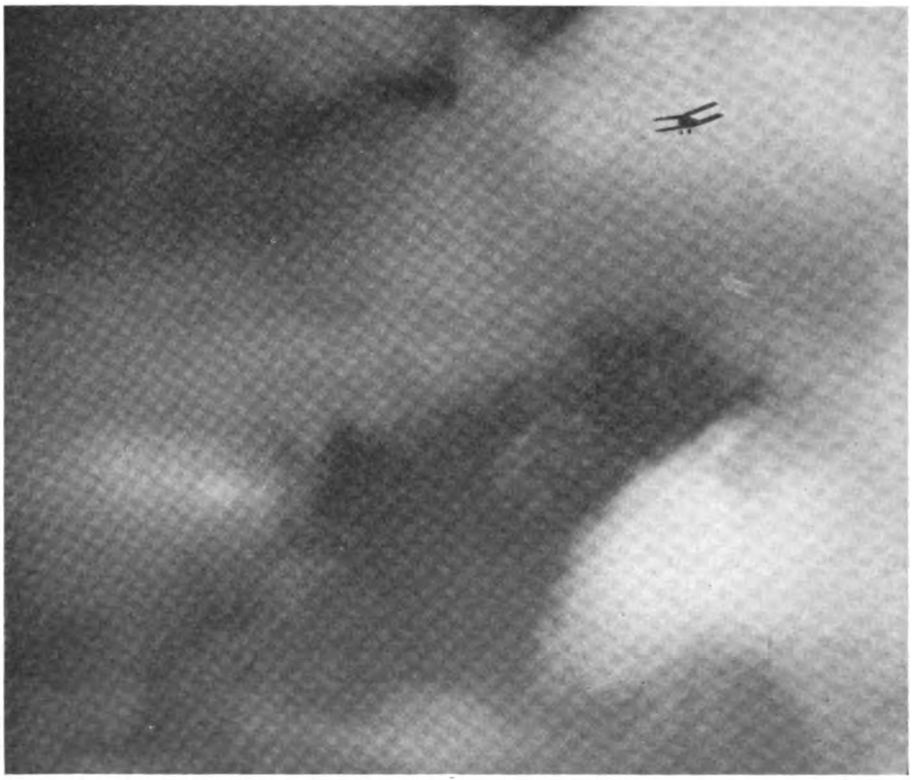
There was a time when we both hoped and believed that with the progress of science our meteorologists would some day be able to predict weather changes far ahead—for weeks or even months. But the latest scientific concepts of such men as Bohr, Eddington, Bridgeman, and Langmuir make it necessary to abandon such a belief.

The great trade winds and monsoons are remarkably constant over a fairly wide range; but, in general, weather changes of the future must forever remain unpredictable, for the simple reason that new conditions are constantly being created.

These modern scientific concepts make one modify one's confidence in the Present being the Child of the Past and the Parent of the Future. They throw a new light on evolution and open up a new vision of the unlimited possibilities for the future of all created things—including man. It may make our meaning clearer if we imagine our weather predictions all complete for a given date and place as accurately as man is capable of determining them. Then high up in some clouds there is a new condition created in some little atom in a particular molecule of water vapor. This newly created condition may cause precipitation to start at a particular time in a definite part of our cloud, an event which is quite unpredictable, but one which may modify our whole weather map. The future must forever remain unknown to man.

From the foregoing, it must be realized that future weather conditions are unpredictable, that is to say, far in advance. But apparently there are no such things as weather changes in the stratosphere. This makes us wonder whether the great commercial highways of the skies will not ultimately be in the stratosphere. With our modern superchargers, means for supplying oxygen and heat to the aviator, and propellers specially designed for operating in the rarer medium, this seems well within the realms of probability.

J. R. H.



Interpretation of Weather Maps

By A. R. STEVENSON, Jr.
Engineering General Department, General Electric Company

The author wrote the following for his own education in the interpretation of weather maps, and as so many of our readers have, or contemplate getting, planes of their own, we publish it as a useful first lesson.—Editor

THE air at the equator is heated by the more direct rays from the sun. As it becomes warmer, it expands, growing lighter and less dense. As the temperature increases, the capacity of the air for holding water vapor increases proportionately. Water vapor is lighter than air. A moisture-laden atmosphere is lighter than a dry atmosphere, due to the replacement of a portion of dry air by water vapor. This warm moist air at the equator rises, giving place to colder denser air which flows in from the north and south.

In a place where light air is rising, the total weight of air in a vertical column is less than normal. Such a region will then be one of low barometric pressure.

This warm moist air, after rising at the equator, spreads out in the upper regions toward the north and toward the south. As it grows colder, it contracts, becoming denser and losing some of its moisture by precipatition.

By the time it reaches either the northern Temperate Zone or the southern Temperate Zone, it becomes heavy enough to sink back again toward the surface of the earth.

These regions where air is sinking have high barometric pressure because of the greater weight of a column of relatively dense air. They are also characterized by clear weather because the air coming down from the upper regions is cold and dry.

These regions of high and low pressure are illustrated in Fig. 1, which also shows a low pressure region at each of the poles. These are probably due to centrifugal force throwing the air outward and upward.

The air leaving the equator has approximately the same peripheral speed as the surface of the earth at the equator. It retains some of this excess sidewise velocity from west to east when it comes down again in the Temperate Zones. This causes an average wind from the west toward the east of approximately 7.5 miles per hour between Chicago and New York.

Similarly, the cold dense air flowing in along the surface of the earth toward the equator has a lower sidewise peripheral speed than the surface of the earth at the equator. Since it does not keep up with the surface of the earth, it has a relative deflection from the east toward the west causing the well-known Trade Winds. As the equator is approached however, the increase in peripheral velocity is less and less, so that the slower moving air, being gradually accelerated by friction with the earth, has a better chance to catch up with the surface of the earth. Thus between the two regions of Trade Winds, there is a region of comparative calm directly over the equator.

The foregoing movements of air can be generalized as follows: Because of the rotation of the earth, winds in the northern hemisphere are deflected to the right and winds in the southern hemisphere are deflected to the left.

In the northern hemisphere, when a north wind passes east of a south wind, as shown in Fig. 2, the rotation of the earth deflects them toward each other and this causes a high-pressure area between them.

On the contrary, when a north wind passes west of a south wind, Fig. 3, the rotation of the earth deflects them away from each other, and this reduces the pressure between them.

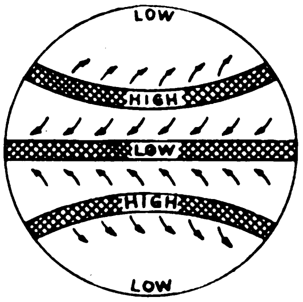


Fig. 1. Planetary Winds

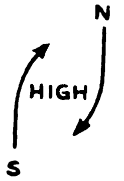


Fig. 2. Clockwise Rotation

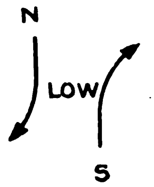


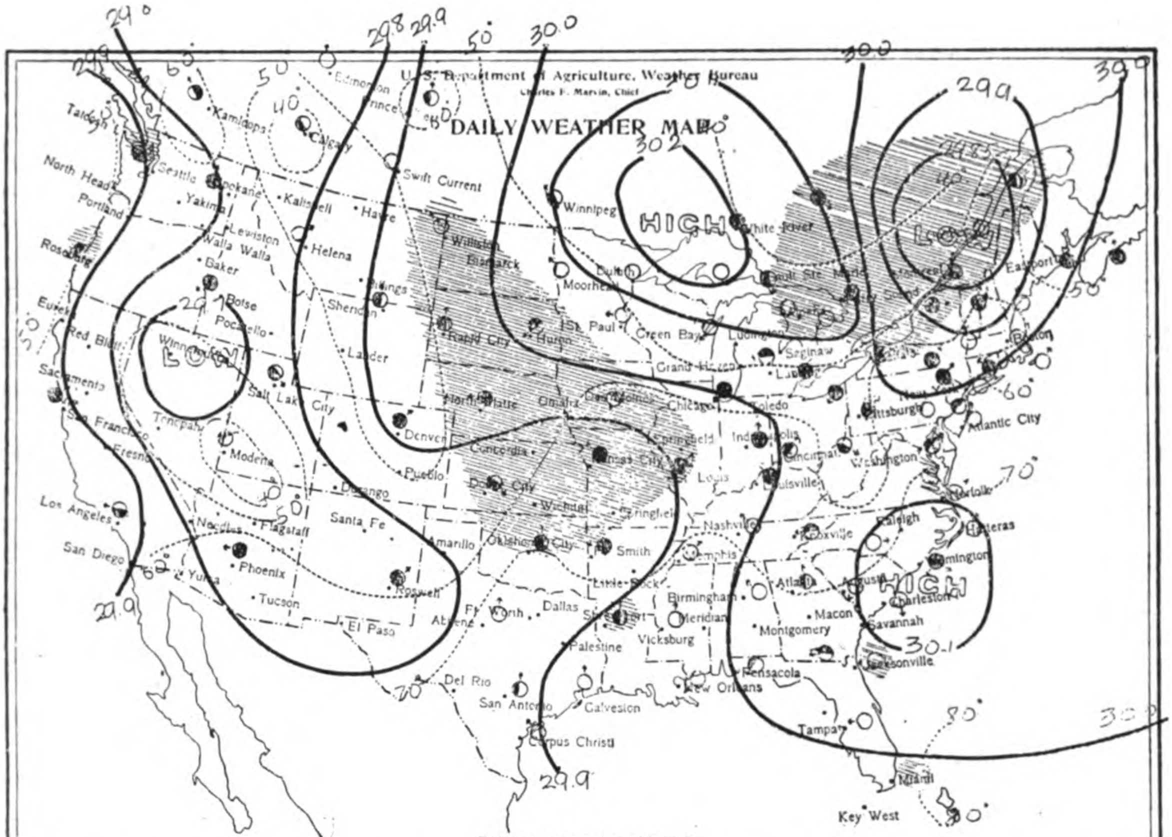
Fig. 3. Counterclockwise Rotation

This can still further be generalized by saying:

The winds revolve in a clockwise direction about the centers of high pressure, and in a counterclockwise direction about the centers of low pressure. If it were not for the rotation of the earth, these winds along the surface of the earth would flow directly from high-pressure regions to low-pressure regions; but due to the aforementioned affects of rotation, the winds in some places actually flow at right angles to the direction in which the pressure changes.

In the weather map, Fig. 4, the full black lines connect points of equal barometric pressure; the arrows represent wind direction; and the dotted lines connect points of equal temperature. A circle with *R* in it means rain.

From the dotted lines showing the temperature distribution, it will be seen that the air in the high pressure areas is colder than the air in the low-pressure


U. S. Department of Agriculture, Weather Bureau
Charles F. Marvin, Chief
DAILY WEATHER MAP
HIGH
LOW
HIGH
LOW
29.8
29.9
30.0
30.2
29.9
30.0
29.85
29.7
30.1
29.9
29.9
50
40
60
70
80
Edmonton
Prince Albert
Kamloops
Calgary
Swift Current
Winnipeg
White River
Sault Ste. Marie
Eastport
Tatoosh
North Head
Portland
Seattle
Spokane
Yakima
Kalispell
Havre
Lewiston
Walla Walla
Helena
Baker
Williston
Bismarck
Moorhead
Duluth
Roseburg
Boise
Pocatello
Sheridan
Billings
St. Paul
Green Bay
Eureka
Red Bluff
Winnemucca
Lander
Rapid City
Huron
Grand Haven
Saginaw
Sacramento
San Francisco
Fresno
Salt Lake City
North Platte
Omaha
Des Moines
Chicago
Toledo
Pittsburgh
Atlantic City
Modena
Denver
Concordia
Springfield
Indianapolis
Cincinnati
Washington
Los Angeles
Pueblo
Dodge City
Kansas City
St. Louis
Louisville
Norfolk
Santa Fe
Wichita
Springfield
Nashville
Knoxville
Raleigh
Hatteras
Wilmington
San Diego
Needles
Flagstaff
Amarillo
Oklahoma City
Fort Smith
Memphis
Phoenix
Yuma
Tucson
Roswell
Little Rock
Birmingham
Atlanta
Charleston
Savannah
El Paso
Abilene
Fort Worth
Dallas
Shreveport
Meridian
Macon
Montgomery
Vicksburg
Palestine
Jacksonville
Del Rio
San Antonio
Galveston
New Orleans
Pensacola
Corpus Christi
Tampa
Miami
Key West

EXPLANATORY NOTES

Observations taken at 8 a. m., 75th meridian time. Air pressure reduced to sea level. ISOBARS (continuous lines) pass through points of equal air pressure. ISOTHERMS (dotted lines) pass through points of equal temperature; ○ clear; ◒ partly cloudy; ● cloudy; R rain; S snow; M report missing. Arrows fly with the wind. Shaded areas show precipitation of 0.01 inch or more in past 24 hours. Wind velocities of less than 10 miles an hour, and amounts of precipitation of less than 0.01 inch are not published hereon.

WEATHER BUREAU OFFICE ALBANY, N. Y.
Room 27, Federal Building Telephones, 3-4794; 4-0815

Friday, June 7, 1929.

FORECASTS TILL 8 P. M. FRIDAY

Albany and vicinity: Generally fair to-night and Saturday; cooler to-night. Gentle to moderate northwest to north winds.

Eastern New York: Partly cloudy to-night and Saturday, possibly showers in extreme south portion; somewhat cooler in central and southwest portions to-night.

Western New York: Partly cloudy to-night and Saturday; slightly cooler to-night.

Northern New England: Partly cloudy, except showers in extreme eastern Maine to-night; somewhat cooler to-night except in extreme eastern Maine; Saturday mostly fair.

Southern New England: Partly cloudy to-night and Saturday, possibly showers on the south coast; somewhat cooler to-night, except in southern Connecticut.

WEATHER CONDITIONS

Showers have fallen in the St. Lawrence Valley, Quebec and eastern Ontario, attending the movement of a depression now centered between Montreal and Quebec. Pressure has fallen slightly in the lower Missouri Valley, and there have been general showers in Oklahoma and Missouri and thence northwestward across the Dakotas. Fair weather has prevailed elsewhere except for a few widely scattered showers. Moderately high and rising pressure obtains over the Lake region, accompanied by cooler weather, and its eastward movement will produce fair and cool weather in this vicinity Saturday and probably Sunday

Temperatures are about normal, except that they range from 3° to 12° below normal in the Lake region and the upper Mississippi Valley.

G. S. Lindgren

Observations taken at 8 a. m. 75th meridian time. First figures indicate highest temperature in the past 24 hours; second figures, lowest in the past 12 hours; third figures, precipitation in the past 24 hours.

Abilene, Tex	88	70	0	Marquette, Mich	60	40	0
ALBANY	69	56	0	Memphis, Tenn	82	70	0
Alpena, Mich	70	38	.30	Miami, Fla	84	74	.02
Atlanta, Ga	80	66	0	Modena, Utah	70	36	0
Atlantic City, N. J.	66	58	0	Montreal, Que	60	48	.38
Augusta, Ga	78	64	0	Moorhead, Minn	72	42	0
Binghamton, N. Y.	70	56	0	Nantucket, Mass	66	52	0
Birmingham, Ala	84	66	0	Nashville, Tenn	84	62	0
Boise, Idaho	72	60	0	New Haven, Conn	72	54	0
Boston, Mass	70	56	0	New Orleans, La	88	76	0
Buffalo, N. Y	64	54	0	New York, N. Y	72	58	0
Calgary, Alberta		32	0	Norfolk, Va	80	64	0
Canton, N. Y	60	50	.30	Northfield, Vt	66	42	0
Cape Race, N. F	.....	34	0	North Platte, Neb	74	58	.36
Charleston, S. C	78	70	0	Oklahoma City, Ok	78	70	.14
Charlotte, N. C	86	62	0	Parry Sound, Ont	60	42	.28
Chicago, Ill	80	50	0	Pensacola, Fla	80	74	0
Cincinnati, Ohio	80	60	0	Philadelphia, Pa	76	60	0
Cleveland, Ohio	76	52	0	Phoenix, Ariz	94	64	0
Cochrane, Ont	62	36	.20	Pittsburgh, Pa	76	62	0
Corpus Christi, Tex	88	76	0	Portland, Me	68	48	0
Denver, Colo	74	44	0	Prince Albert, Sask		56	0
Des Moines, Iowa	78	62	.12	Quebec, Que	60	48	.40
Detroit, Mich	78	48	0	Rapid City, S. Dak	68	54	.02
Dodge City, Kans	78	56	1.32	Richmond, Va	82	62	0
Doucet, Que		38	.16	Roseburg, Oreg	66	48	.14
Duluth, Minn	60	42	0	Roswell, N. M	92	56	0
Eastport, Me	54	40	0	St. Louis, Mo	82	64	1.20
Edmonton, Alb	82	50	0	St. Paul-Minn'polis	80	48	0
Elkins, W. Va	74	46	0	Salt Lake City, Ut	78	56	0
Father Point, Que	56	44	.24	San Antonio, Tex	88	72	0
Fort Smith, Ark	76	66	0	San Francisco, Cal	64	54	0
Galveston, Tex	86	78	0	S. Ste. Marie, Mich	56	40	0
Gr'd Rapids, Mich	78	46	0	Scranton, Pa	70	48	0
Green Bay, Wis	78	46	0	Seattle, Wash	58	50	.22
Halifax, N. S	52	46	.14	Sheridan, Wyo	68	42	0
Ham'ton, Bermuda	76	68	3.52	Shreveport, La	88	70	.10
Harrisburg, Pa	76	56	0	Southampton, Ont	....	40	.14
Hatteras, N. C	80	64	0	Spokane, Wash	74	56	0
Havana, Cuba	..		.....	Swift Current, Sask	78	44	0
Helena, Mont	74	48	0	Tampa, Fla	90	70	0
Huron, S. Dak	76	50	.02	The Pas, Manit	60	44	0
Indianapolis, Ind	80	64	0	Thomasville, Ga	88	68	0
Ithaca, N. Y	70	52	.01	Vicksburg, Miss	84	70	0
Jacksonville, Fla	80	72	.18	Washington, D. C	80	60	0
Kamloops, B. C	86	64	0	White River, Ont	46	30	0
Kansas City, Mo	70	60	.04	Williston, N. Dak	74	54	.04
Knoxville, Tenn	82	62	0	Wilmington, N. C	82	64	0
Los Angeles, Cal	66	54	0	Winnemucca, Nev	70	48	0
Louisville, Ky	82	64	0	Winnipeg, Manit	62	40	0

LOCAL DATA

TEMPERATURE—Mean yesterday..67
Departure from normal......− 9
Departure this month.........−51
Departure since January 1st . +204
Highest this date..... 95 in 1925
Lowest this date.......40 in 1878

PRECIPITATION—
Total this month to date......0.33
Departure from normal.....−0.51
Departure since Jan. 1st....+4.20
RIVER—Stage at 8 a. m., feet.....3.7
Flood stage, 12 feet; normal....3.7

Fig. 4. Weather Bureau Map with Supplementary Data

areas. As this cold high-pressure air flows into the warmer low-pressure regions, the cold air being heavier stays below forcing the warmer air to rise over it.

As the column of air rises, it expands, owing to the rarefied state of the upper regions, the expansion being accompanied by loss of heat which, together with the prevailing temperature, causes the water vapor to be condensed. Thus there results either fog, clouds, rain, snow, hail, frost, or dew.

The wind direction is responsible for the great difference in temperature and moisture between the two sides of a low. On the east side, the wind blows from some southerly quarter, bringing with it warm moisture-laden air and a rise in temperature. On the west side, a northerly wind prevails, resulting in cold dry weather.

The foregoing is summed up in a paragraph on page 35 of the Report No. 13 of the National Advisory Committee for Aëronautics, as follows:

"*The Rain Area of the Low.*—A careful study of the air circulation in the vicinity of an area of low pressure indicates that the air of the southerly current is deflected most toward the pressure minimum and converges most in front and to the north of the center of low pressure, and that the air of the northerly current is deflected most and spreads out over the earth's surface to the south of this line. Since precipitation results directly from the ascent of the relatively warm, moist air of the southerly current, these two factors operate to place the center of the precipitation area in the front, possibly a little to the south, of the center of low pressure. Almost any weather map in which a well-formed low is illustrated will show the rain area centered in the front half of the low.

"*Other Rain Areas.*—There is, as a rule, but little mixing of the northerly and southerly currents across the ridge of high pressure. Mixing may occur here, because of the deflecting action of the earth's rotation and in spite of the opposing pressure gradients. When it does, small precipitation areas may be found to the northeast or to the south of the center of high pressure, where the warmer, moister air of the southerly wind has risen over the colder air of the northerly."

These low and high-pressure areas travel from west to east across the country with the speed and direction of the air at an altitude of two or three miles. The average velocity of such movements is 25 miles per hour from the west toward the east, the low pressure areas traveling two or three miles an hour faster than the high pressure areas.⁽¹⁾ Most low pressure areas leave the country at the northeast, usually by way of the Great Lakes and the St. Lawrence, or by way of the Ohio River Valley or by way of the Gulf and Atlantic Coasts.

The passing of a low-pressure center south of an observer, consistent with the foregoing, would have the following effects:

1st: Easterly wind—cirrus clouds.
2d: Followed by lower clouds.
3d: Precipitation.
4th: As wind changes to northwest by way of north, clearing and cooler weather.

This is stated by W. R. Blair⁽²⁾ as follows:

"When the wind sets in from points between the east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south or east of the observer within 12 to 24 hours, with wind shifting to northwest by way of north. The rapidity of the storm's approach and its intensity will be indicated by the rate and the amount of the fall in the barometer."

The passing of a low-pressure center north of the observer, according to the same authority,⁽²⁾ would be as follows:

"When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or north of the observer within 12 to 24 hours, with wind shifting to northwest by way of southwest and west.

"*The Thunderstorm Region.*—A north and south line through the center of a low-pressure area lies approximately in the boundary between the warm air mass to the east and the cooler air mass to the west of it. It is in such a region that thunderstorms and tornadoes are most likely to occur in the summer months. Temperature and other conditions most suitable for the development of these local storms are found to the south of the center of the low-pressure area. There is much more likelihood of the cold and warm air mixing, and therefore of thunderstorms, in the south half of the trough of low pressure than in the corresponding region of the ridge of high pressure. This is because the air tends to flow in the direction of decreasing pressure. Certain parts of the country are seldom traversed by low-pressure areas and seldom, therefore, experience thunderstorms or tornadoes, while in other regions these more local storms are quite frequent. Bad flying conditions are likely to be experienced in the region of turbulence to the south of a low-pressure area, especially in the summer half of the year."

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(1) I do not know why the low-pressure areas travel faster than the high-pressure ones. If the opposite were true, it would seem more logical.

(2) Meteorology and Aëronautics—Report No. 13 of the National Advisory Committee for Aëronautics.

The Use of Electric Power in Production of Building Stone

By **J. F. FRENCH** and **H. S. BRIGHTLY**
Electrical Engineer in Charge of Electric Equipment   Director of the Architects' Service
Indiana Limestone Company

This article, together with the remarkable illustrations, will show the modern methods used in one of man's oldest industries—the fashioning of stone.—EDITOR

THE Indiana Limestone Company of Bedford (Indiana) was formed in 1926 by the consolidation of twenty-four quarry and mill operating companies, including building stone quarries, saw mills and stone cutting plants in the Colitic Limestone District of southern Indiana. These were formerly operated by separate firms and corporations and included most of the old established quarries in the district from which the famous building stone has been produced for several generations. With a capital of over $46,000,000, and the personnel and experience of these twenty-four companies combined, the company has come to occupy a dominating position in its special sphere of operations.

The industry forms a most important factor in the field of building construction; and with the constantly increasing demand for better building material, natural stone, and especially limestone, has been employed to a constantly increasing extent; both because of is structural merits and its fine weathering properties. It is interesting to note that the product of this stone district now constitutes over 65 per cent of all the finished building stone used throughout the United States, embracing stone of all kinds including granite, limestone, sandstone and exterior marble. Of this great annual production, which at present aggregates over fourteen million cubic feet, the Indiana Limestone Company will furnish well over 60 per cent, or approximately 43 per cent of the nation's finished building stone requirements. Although the company's business is primarily a quarrying business, it also owns a number of the largest cut stone plants in the district, cutting and finishing about 35 per cent of the quarried stone which they produce; the remainder being supplied in the form of rough blocks, sawn slabs or semi-finished products to the cut stone plants and stone yards throughout the United States and Canada.

In reorganizing its quarries and plants the new corporation decided to employ electric power to a greater extent than ever had been attempted before in a similar industry. This involved scrapping, and replacing with modern equipment, a great number of the older types of quarry channelling machines. The rebuilding and modernizing a great number of machines and equipment is still in progress.

The Company now has 1325 electric motors installed and in operation; the connected load amounts to 35,600 hp.

As, practically speaking, all of the electric equipment in a quarry is exposed to the weather at all times, it has been found by experience that continuous operation and maximum production during the quarrying season can only be assured by overhauling and reconditioning in the repair shop each winter.

By a carefully worked out scheme of electric power distribution in the quarries all past troubles due to low voltage have been eliminated. These troubles in the past resulted in prohibitive maintenance costs and in always having a considerable amount of machinery idle while waiting for repairs.

Banks of transformers are now located adjacent to all load centers and the cables are of sufficient capacity and are properly installed. On the top of the quarry ledges the secondary distribution wires are mounted on vertical racks and are carried on lines of stub poles.

All of the secondary distribution system from the transformers to the quarry and to the cutting or channelling machines on the quarry ledges is carried out through the medium of large portable drag cables of standard manufacture. Heavy-duty safety switches and fuses of standard design are used ahead of all such cables and also ahead of the individual channelling machine drag cables.

Final distribution on the working ledge is made through a home-made switch stand on which are mounted two 100-amp. safety switches and fuses and one 4-way junction box. The individual machine drag cables are 175 ft. in length; they have three conductors of No. 4 wire and are fed from the above mentioned 100-amp. switches. The electric motors on the channelling machines are 25-hp., 220-volt, 3-phase, 60 cycles, 900 r.p.m. slip-ring motors arranged for variable speed control. These motors are especially manufactured to withstand the extremely hard operating conditions. The switch stands mentioned above are each connected to the power drag cables which run down into the quarry and they can be arranged in any combination to suit operating requirements; which depend upon the number of machines being used on any one track. In the larger quarries it requires several of these large main cables to handle the total load. In every quarry it is also necessary to use a few direct-connected motor-driven centrifugal pumps to get rid of the water and slush.

This slush is a liquid mud being composed of ground limestone and water. These centrifugal pumps are provided with either a 30 or a 50-hp. squirrel-cage motor and with automatic control. The service on these pumps is quite hard as some of them are starting and stopping continuously during the working day. The distribution to these pumps is made at 220 volts, 3-phase, and 60 cycles by means of three-conductor portable drag cables, which are connected through a safety switch to the pole line at the top of quarry hole. The lifting of all the stone in the quarries is done by means of single-mast (either wood or steel) guyed derricks having either a 60 or 75-ft. boom. These are operated by variable-speed power riggings which are driven by standard 3-phase 60-cycle motors operating on 220 volts and running at 900 or 1200 r.p.m. They are arranged for gear drive with manual control. In large quarries there are sometimes from 15 to 20 of these derricks, and they are operated from power lines carried on standard pole-line construction direct from the various banks of transformers. Sometimes the cross arms or vertical racks are fastened directly on the top of the rock or grout piles where it is impossible to plant a pole. Derricks similar in design, but in some cases with taller masts and longer booms, are used in the stacking yards.

The load-factor, and therefore the power-factor, are invariably poor in stone quarry work but a gradual improvement in these two factors is constantly being worked out.

One serious technical difficulty in a quarry is to provide a proper electric ground for all the equipment. The very physical nature of a stone quarry prohibits ordinary means of grounding and in the majority of cases it is found necessary to carry a grounding system to a place remote from the quarry and even then it is hard to get anywhere near 100 per cent efficiency.

All power is now purchased, the supply company also furnishing, installing, and maintaining all the transformers. A total of 100 banks of transformers is at present installed which have an aggregate capacity of 20,500-kv-a. The power is supplied at 4100 volts, 3-phase, 60 cycles and the supply company's point of delivery is considered as being at the secondary side of the transformers. The energy at the secondary of the transformers is 220-volt, 3-phase, 60-cycle. Most of the metering is done on the primary or 4100-volt lines. Energy is brought to the quarry localities from three incoming 33,000 and 66,000-volt transmission lines. These transmission lines have, practically speaking, given 100 per cent continuity of service. For all the quarries and mills together the average monthly consumption of energy amounts to 1,700,000 kw-hr. with an average load of 8600 kw.

Since the policy of purchasing all power was put into effect in the quarries and mills, a saving of one cent per kw-hr. has been effected as compared with costs when a substantial portion of the power used was generated by the company's several power plants. The splendid spirit of coöperation shown by the power company has led to marked improvements in the voltage conditions and in the character of service and led to a great reduction in lost time due to service interruptions. Every effort has been made to modernize the various motor applications as rapidly as possible and the simplification and standardization of both apparatus and machines has led to a marked improvement in operating conditions.

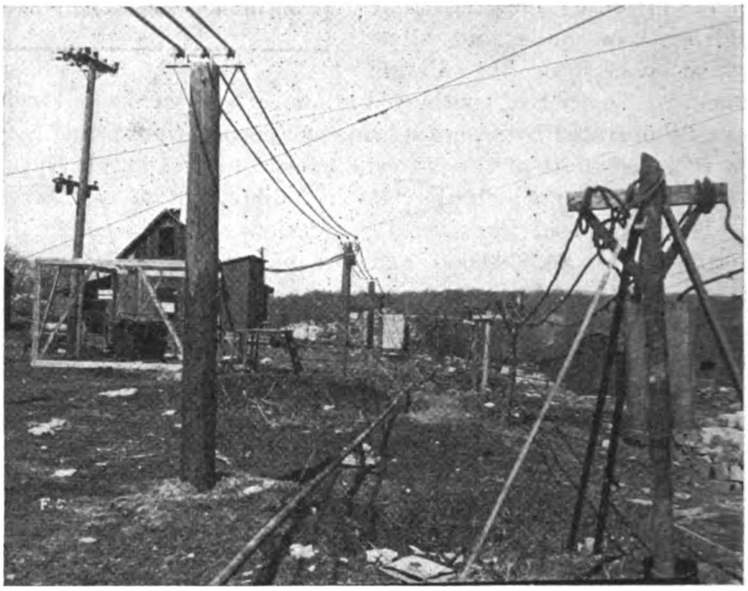

Fig. 1. Showing Manner in which Power Lines Are Carried to Quarry Ledge from Local Transformer Station. To the left are shown the power lines brought to the quarry transformer station at 4100 volts and in the center of the picture the modern system of carrying the three 220-volt power lines resting on insulator racks on top of poles, distributing the power to the various quarry ledges for operation of the channelling machines. To the right of picture is shown the old crude method of carrying power lines without suitable insulation

The modern stone plants are now housed in all steel, stone, and glass buildings with fireproof roofs. These buildings are approximately 600 ft. long and 140 ft. wide, composed of two sections the main one of which is 75 ft. wide and usually about 40 ft. high to enable the operation of the overhead electric cranes; the secondary part consists of a lean-to section from 50 to 60 ft. wide for the installation of the machines. In a mill of this type over 75 per cent of the side and end walls are composed of steel sash and glass construction, providing ample light throughout the entire mill for all classes of work, including the finest carving.

The usual installation in such a mill consists of six gang saws, twelve to sixteen stone planers, three or four diamond saws, a milling machine, and one or

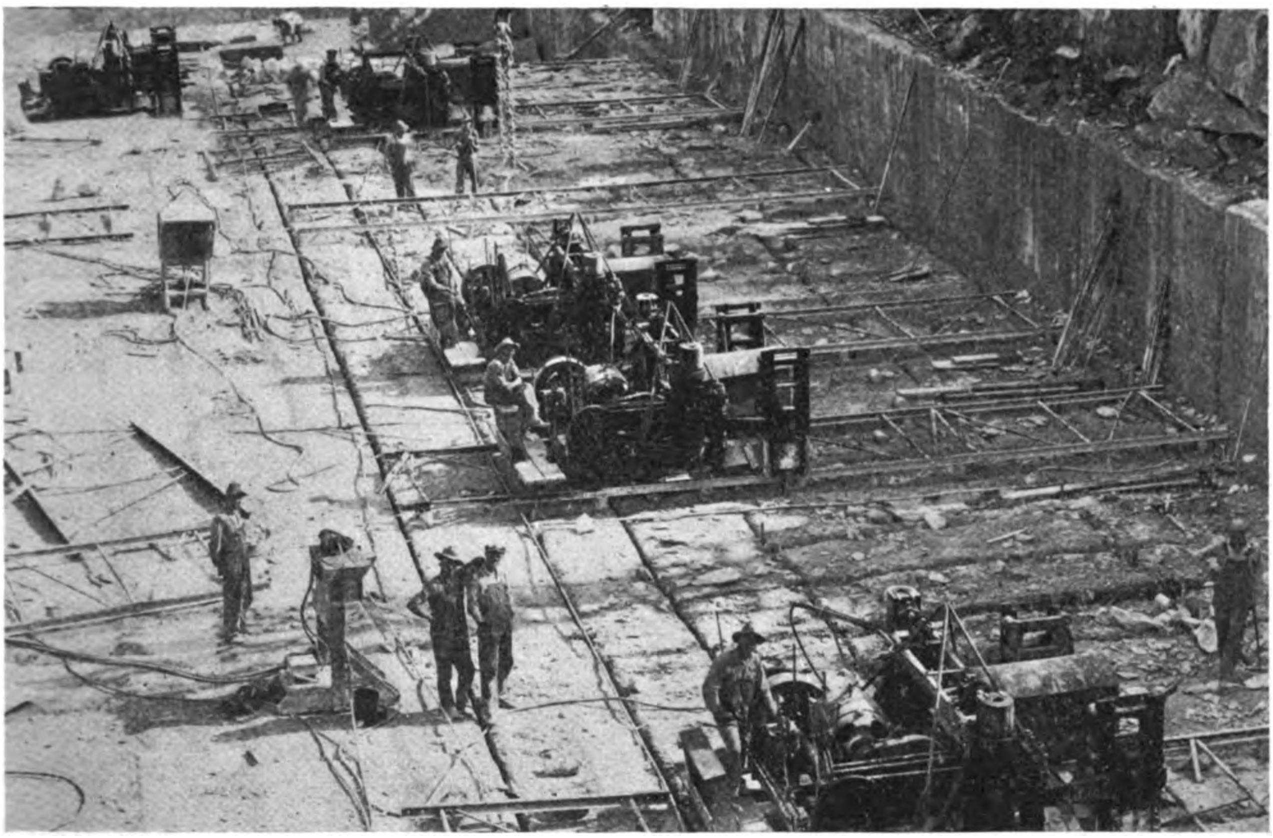

Fig. 2. View in Quarry, Showing the Most Modern "New Bedford" Type of Double Electric Driven Channelling Machines with Power Cables from Portable Switch Stands. Note the flexibility of power transmission which must accompany the installation of this type of machinery. All cables are of standard portable type

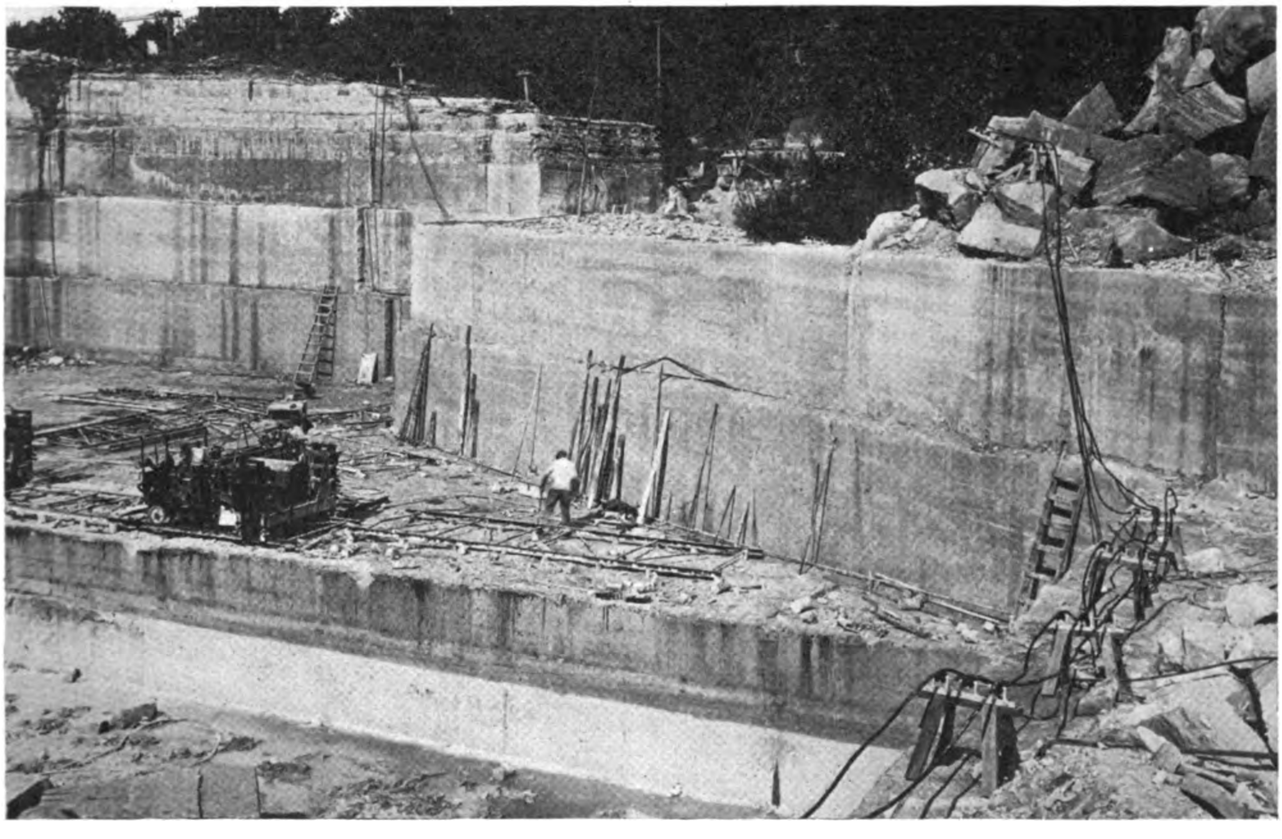

Fig 3. View in One of the Quarries, Showing the Way in which Power Line Cables Are Carried on Insulator Racks Attached to Trestles. This line is for supplying power to the centrifugal pump used for keeping the quarry holes free of water. An installation of this kind is always temporary

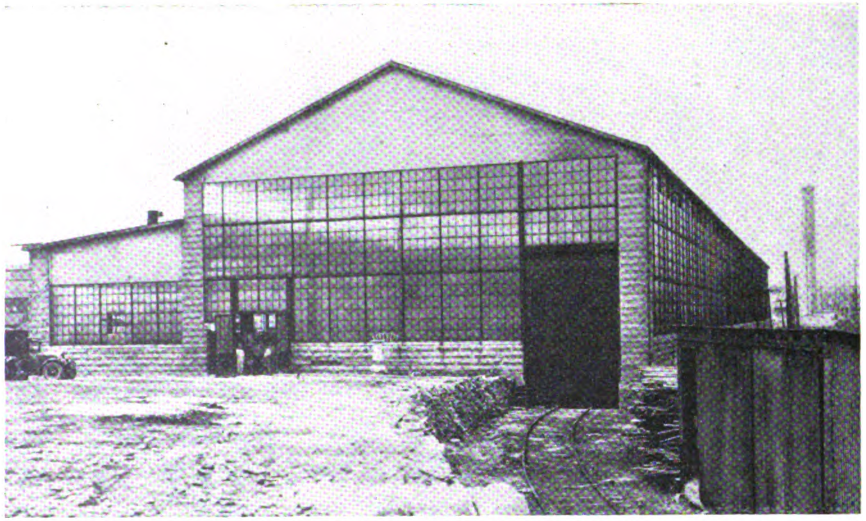

Fig. 4. Modern Cut Stone Mill. The walls are largely of glass in steel sash. In most mills of this type the main section, 400 to 600 ft. long, is provided with a 70-ft. span tramway, and at least four travelling cranes

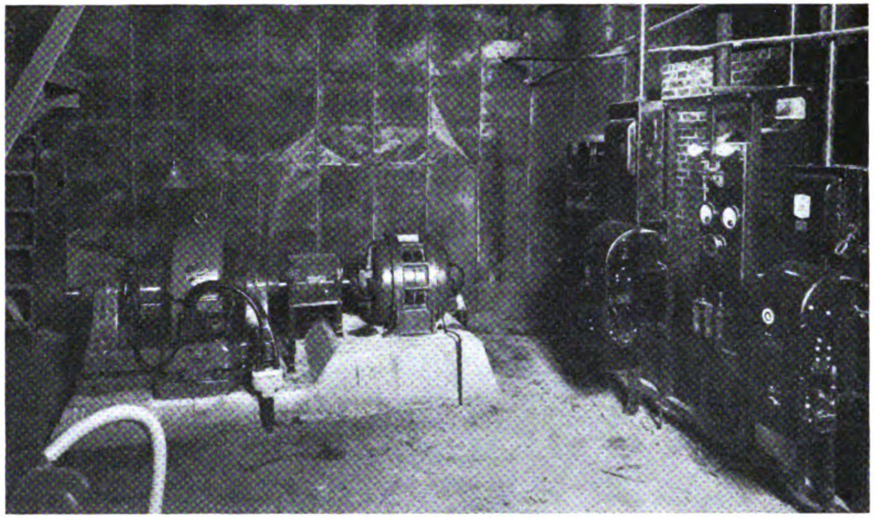

Fig. 5. View of Motor-generator Set and Control Equipment for Purpose of Supplying 220-volt Direct Current for Crane Operation at One of the Mills

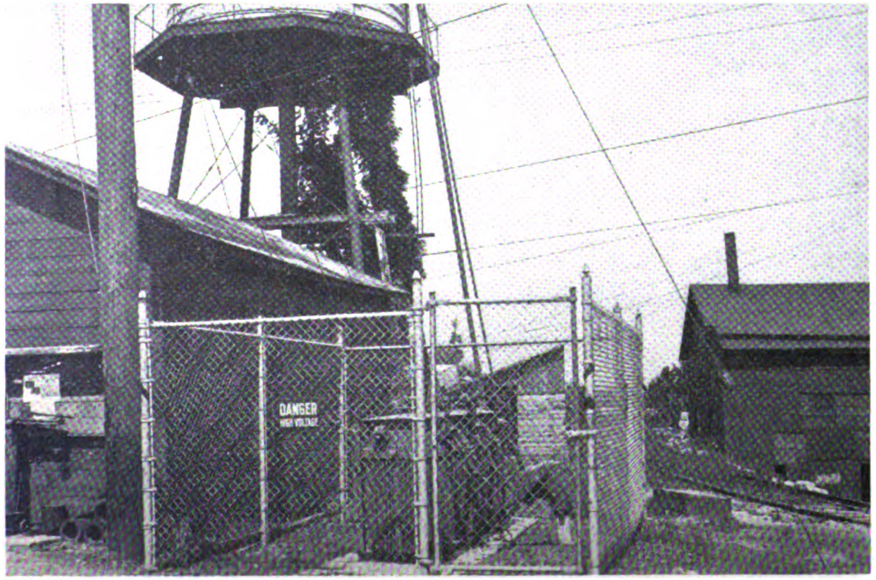

Fig. 6. A Modern Transformer Bank for Serving One of the Saw Mills. Power is brought in at 4100 volts and distribution is made at 220 volts, 3-phase

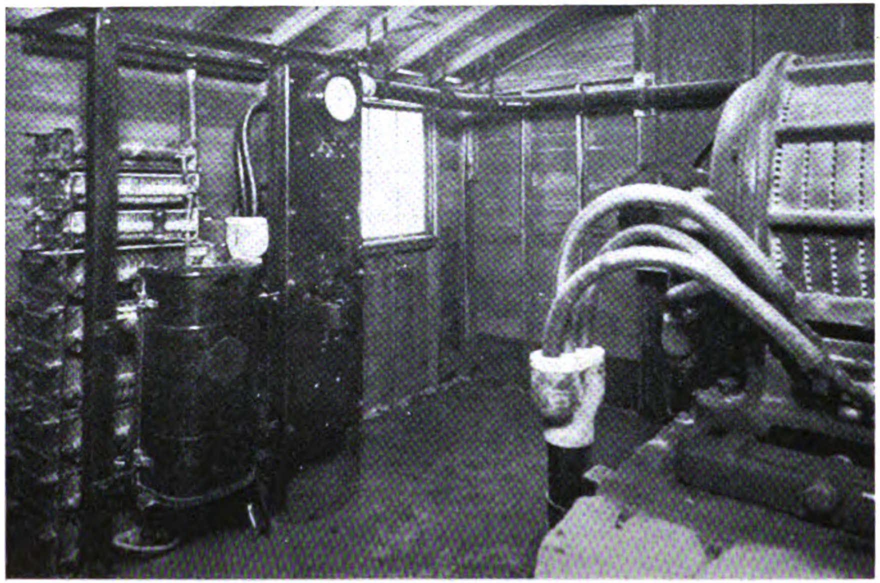

Fig. 7. Control Equipment for 150-hp. Slip-ring Motor Driving a 9-gang Saw Mill at One of the Quarries

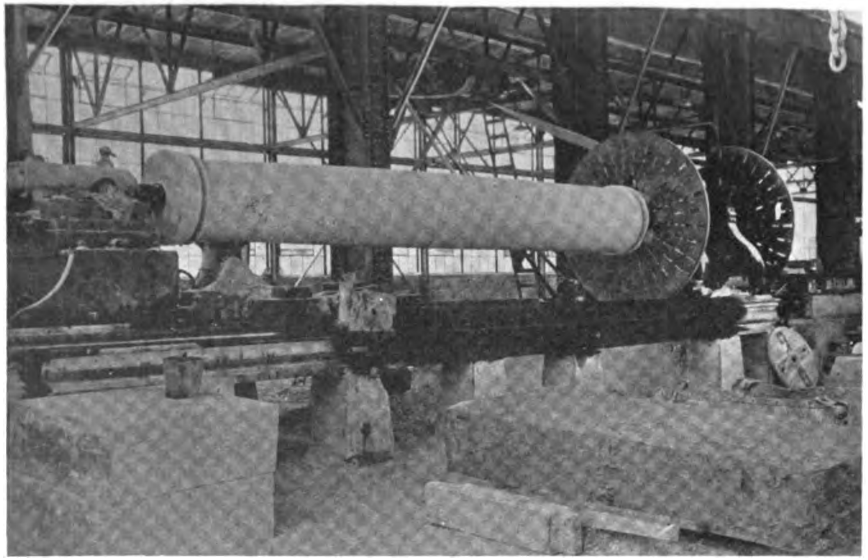

Fig. 8. A Lathe for Turning Monolithic Column Shafts, Operated from a Countershaft Driven by a 10-hp. Variable-speed D-c. Motor. In this and other operations, the shaping of stone resembles the machining of large cast-iron and steel parts

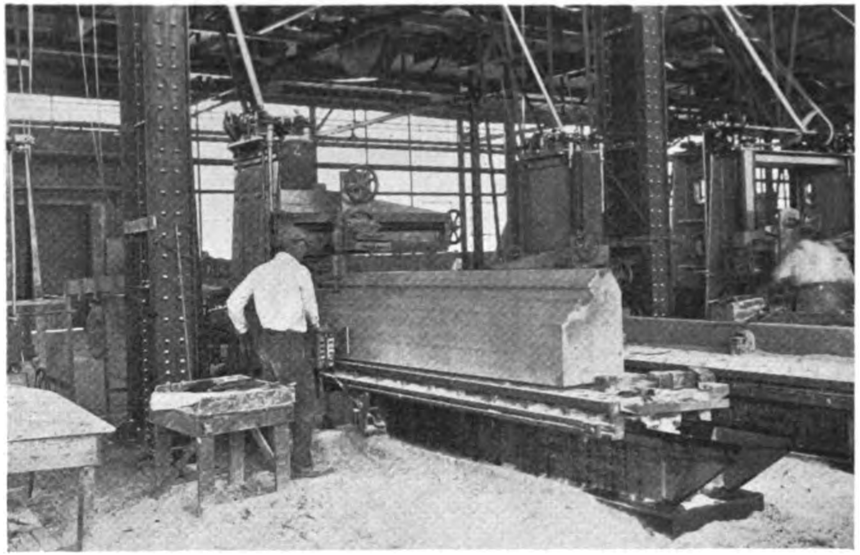

Fig. 9. View of Planer Cutting Gothic Moulding on Large Member This is one of a group of seven double-bed planers of this type which are operated from a line shaft arranged for group drive with one 75-hp. standard cage-type motor

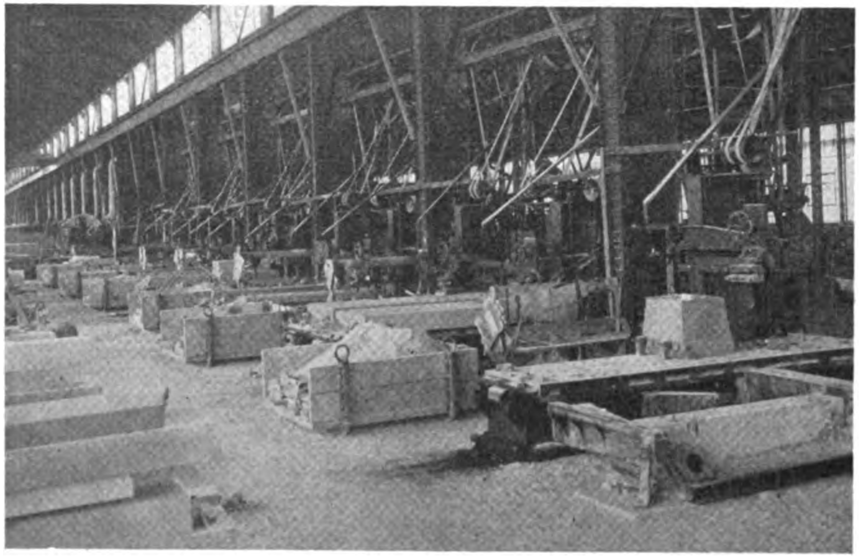

Fig. 10. View of Planing Department in One of the Large Cut Stone Mills, Showing Double Bed Planers. Planers are arranged for group drive driven from one main-line shaft operated by 75-hp. cage-type motor. There are five double-bed and two single-bed planers in this group

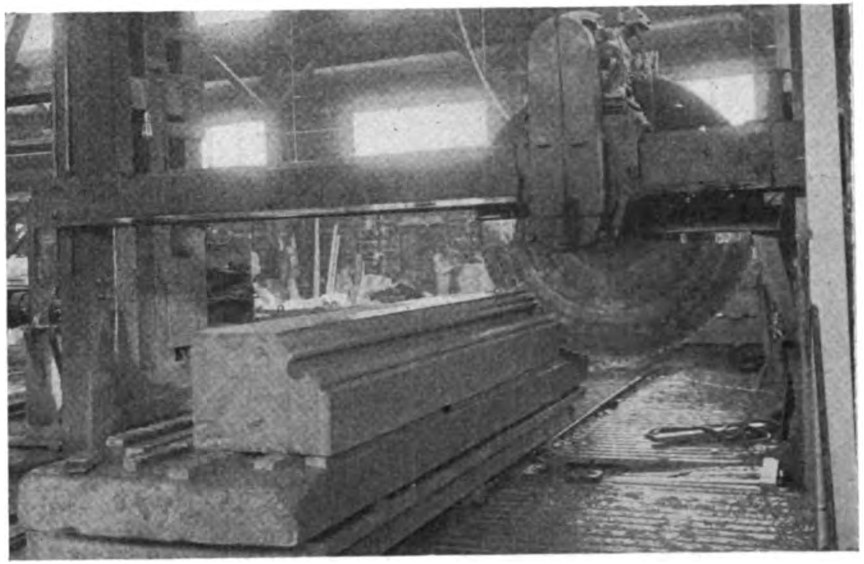

Fig. 11. View of Large Diamond-tooth Circular Jointing Saw Cutting Moulded Member to Length. The 60-in. blade of diamond-tooth saw is driven by standard 25-hp. motor, while the feed and adjustment is driven by standard 3-hp. motor. The teeth of these saws are inserted steel castings carrying commercial black diamond cutting points

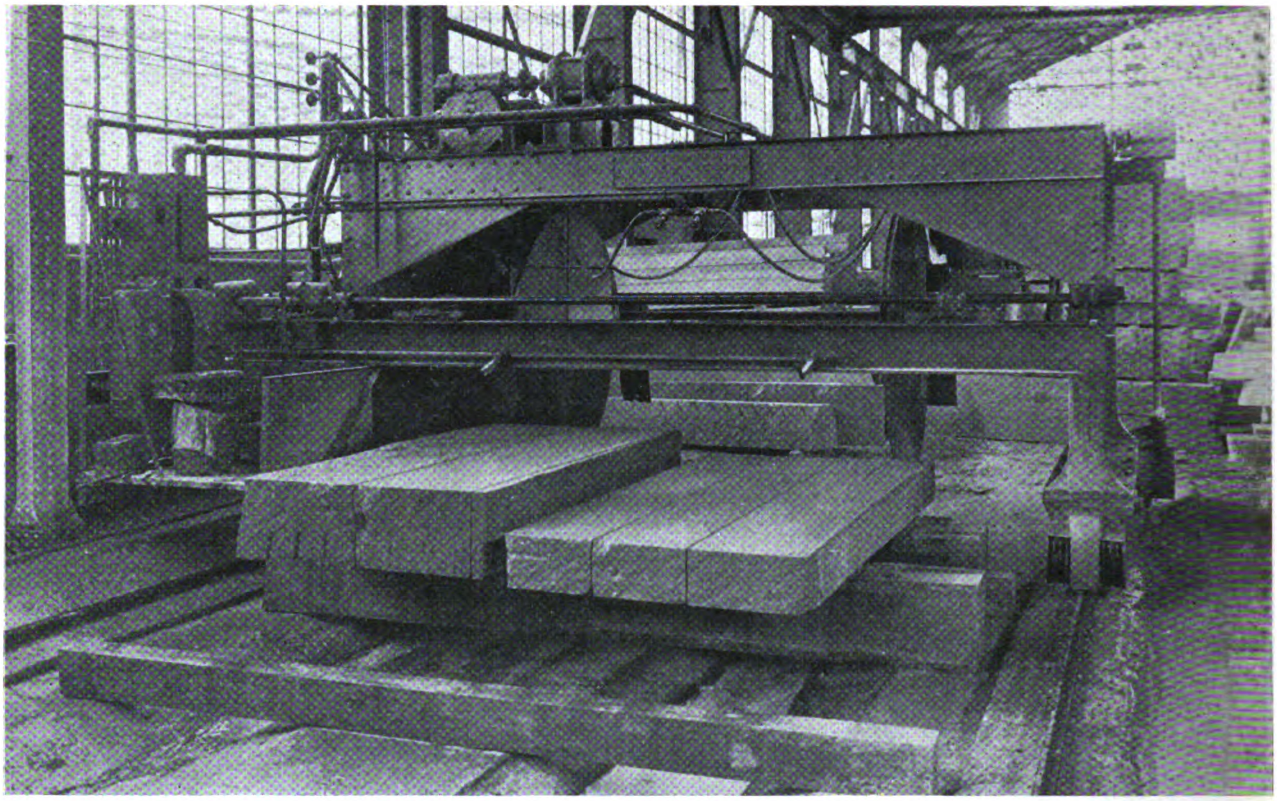

Fig. 12. Gantry Saw Operating Two 72-in. Diameter Diamond-tooth Circular Rip Saws. This Gantry saw has a track span of 16 ft. 6 in. and a cutting travel of 56 ft. The drive shafts of the saws, which are separate, are each driven by a standard cage type of 30-hp. 900-r.p.m. motor through means of chain reduction. The travel of machine or feed, as well as the movement and adjustment of saws is handled by two separate motors, a 7½-hp. 900-r.p.m. driving Gantry feed, and a 5-hp. 1200-r.p.m. operating saw adjustments. The power is transmitted to this type of saw by means of a set of standard crane-type trolley wires shown overhead in upper left of picture

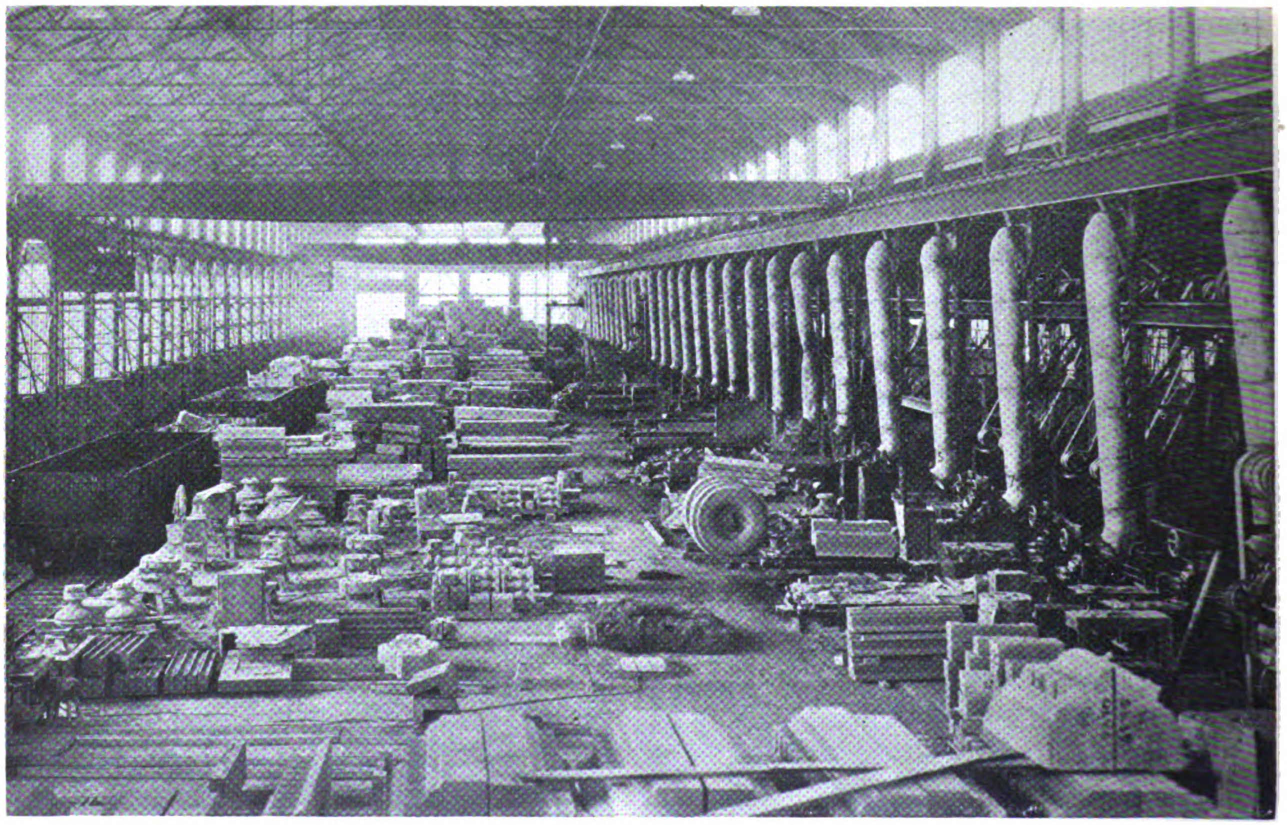

Fig. 13. General View of One of the Large Cut Stone Mills, Showing the Electric Travelling Cranes Having a 70-ft. Span. These cranes are of the three-motor type, using standard 220-volt direct-current crane-type motors. All of the larger mills, of which this is an example, will have at least four of these travelling cranes

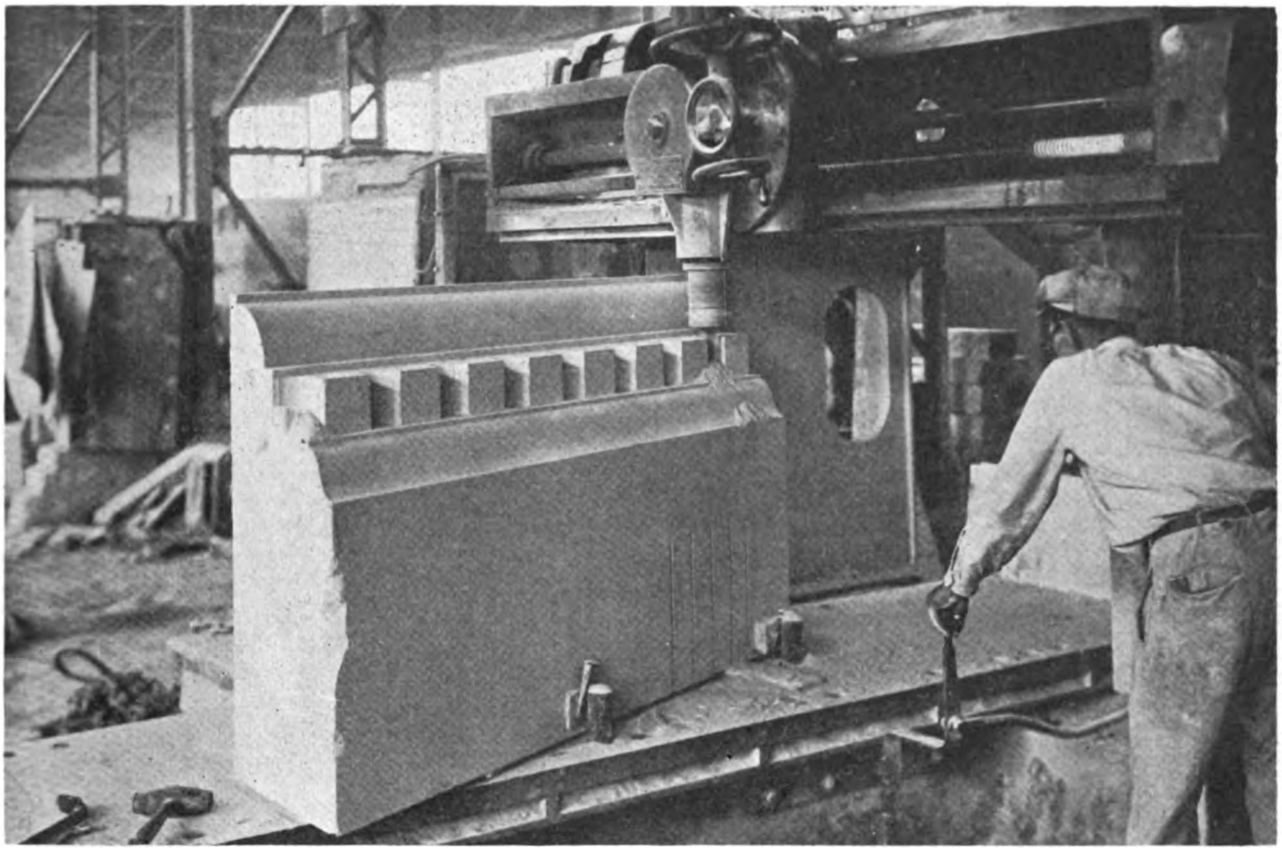

Fig. 14. View of Milling Machine Cutting Dentils in Classical Cornice Member. Such machines are operated with two motors. The motor for milling the head is usually a 10-hp. variable speed slip-ring type motor. That for feed and adjustment is usually a small standard cage-type motor

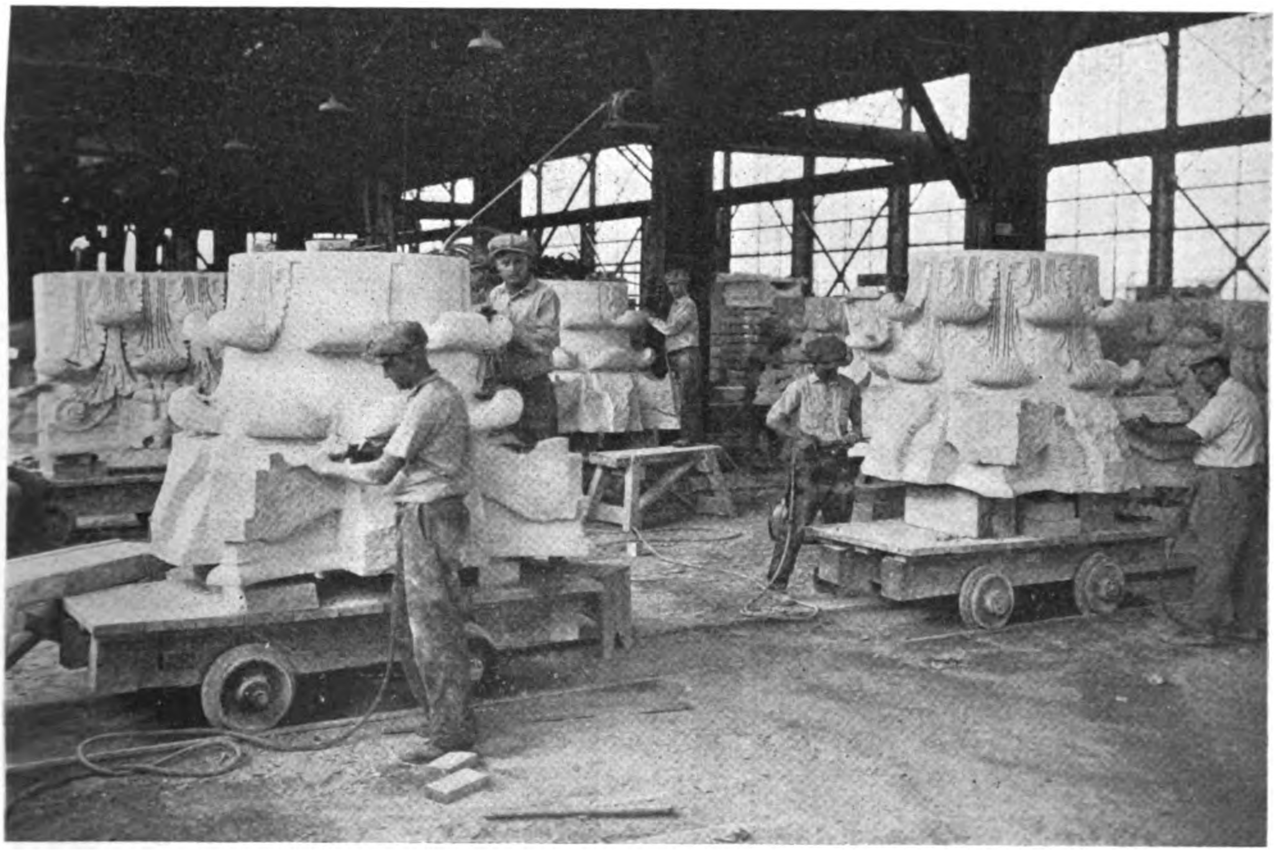

Fig. 15. View in the Cutting Department of One of the Mills Showing Carvers at Work on Large Corinthian Capitals, All Carving Being Done by Air Chisel

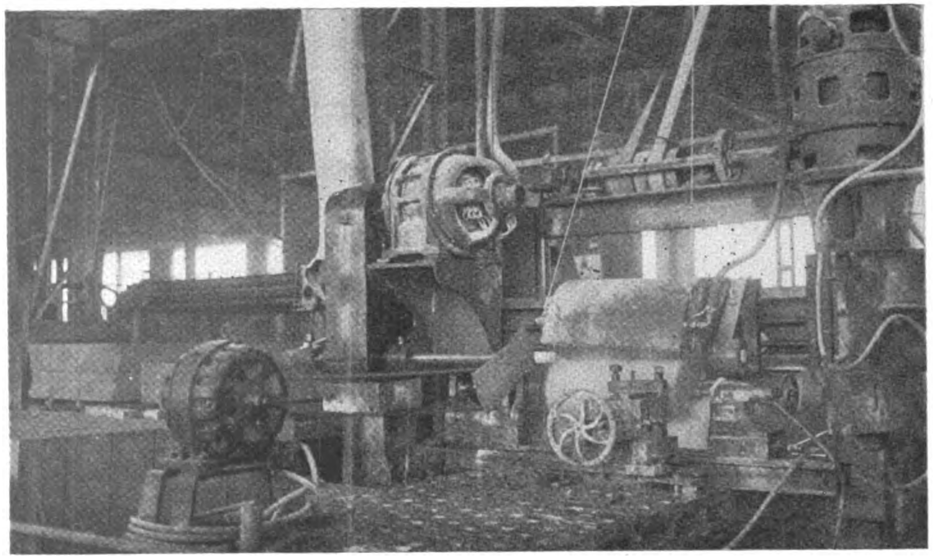

Fig. 16. View of Carborundum Planing and Moulding Machine. The carborundum wheel of this machine is driven by a 75-hp. slip-ring motor, while the feed and adjustment of the machine is driven by a 40-hp. slip-ring motor. These machines have attachments for circular work such as balusters, the mandrel of which is driven by a separate motor

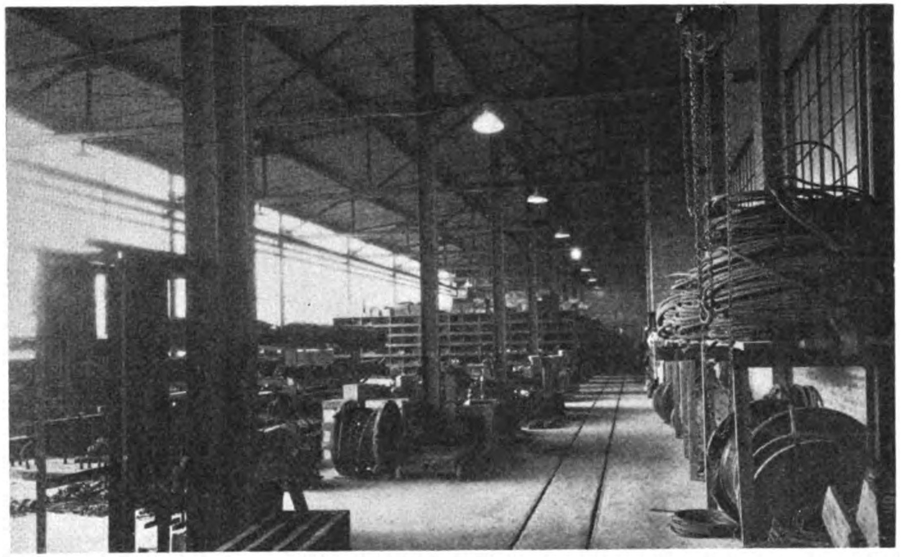

Fig. 17. View of Electrical Supplies and Parts Storeroom Adjoining the Electrical Shop Shown in Fig. 18. In this supply room a complete supply of fittings and material is kept on hand for the repair and rebuilding of motors, power lines, and other electrical equipment of the mills and quarries

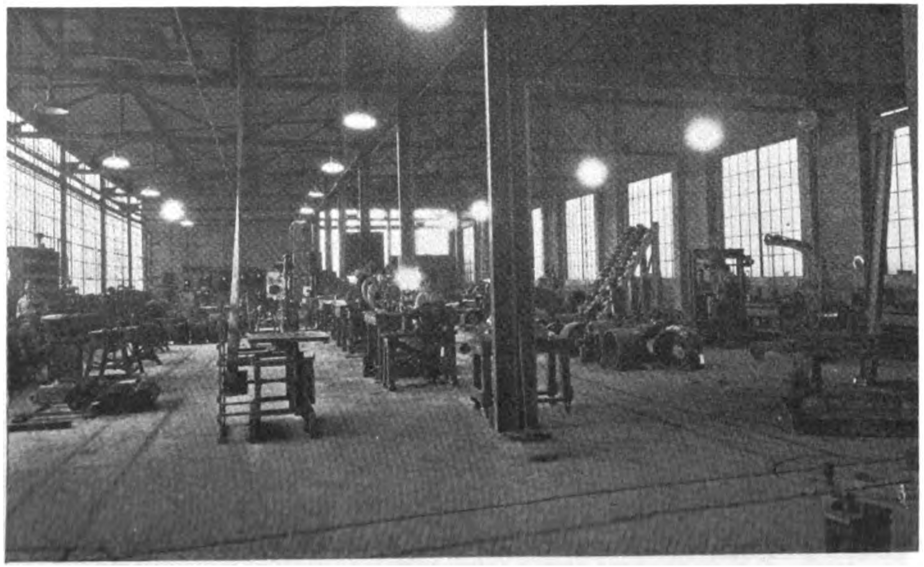

Fig. 18. View of Electrical Shop Described in Detail in This Article. The motor repairs of every nature from all of the quarry and mill properties are centralized in this one shop

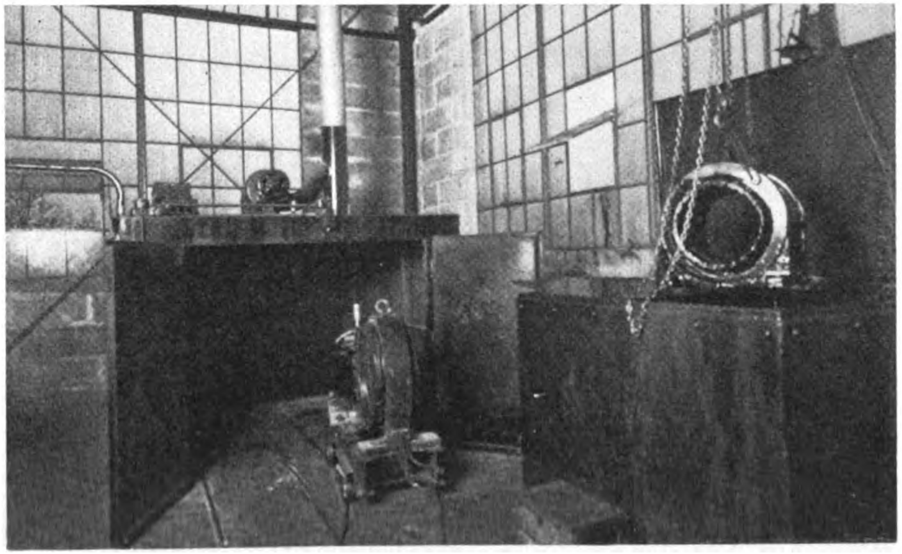

Fig. 19. View of Electric Oven in Repair Shop for the Baking of Armatures and Field Coils, Showing Varnish Dipping Tank at the Right

two lathes; and possibly a carborundum planer or rubbing bed and a diamond drag saw.

It is interesting to note that the limestone is worked in practically the same manner as a large casting of iron or steel. Ample room has also been provided in each mill for the banker stands of from 12 to 30 stonecutters and carvers, as well as sufficient storage space for the large "mill blocks" of stone from the quarries, and a considerable quantity of finished material that must be stacked awaiting shipping orders. Provision is always made for the necessary blacksmith shop for forming and sharpening the tools, and often also a general machine repair shop. Usually there is an air compressor of 500 cu. ft. capacity, belt driven by a 75-hp. electric motor. This compressor supplies air at 100 lb. pressure for various purposes but chiefly for cutting and carving the stone which is done with compressed-air hammer-operated chisels.

The usual crane equipment in such a mill consists of four or five large overhead traveling cranes with a space of 70 or 75 ft. in the newer mill and 60 ft. in the older mills, ranging in capacity from 5 tons to 25 tons. Some mills are equipped with a-c. cranes and others with d-c. There are at present a total of 102 of these overhead cranes in operation.

In the mills or cutting plants it is usual to arrange the gang saws in groups of six for operation by a single electric motor, usually of 75-hp. capacity; while some of the quarry saw mills have ten gang saws in two groups of five each. The line shaft for this type of drive is mounted on either roller or ball bearings.

From twelve to sixteen planers—*i.e.*, six to eight double-bed machines—are usually operated on a group drive with a 75-hp. motor. Diamond saws have individual motor drive using two motors, a small 2 or 3-hp. unit for the feed work and either a 20, 25, or 30-hp. motor to drive the saw blade mandrel, depending upon the diameter size of the blade. A 72-in. blade requires a 30-hp. motor; and these blades are usually driven through the medium of a chain. Experience has shown that it invariably pays to install an ammeter in the circuit of all blade drive motors. This enables the operator to determine just how fast to feed his blades into the block of stone. It may be noted here that the depth of cut and texture, or density, of the particular grade of stone being cut are always important factors in the stonecutting operations.

It is usual to provide the milling machines with individual motor drives with two motors in each case. A separate drive is always provided for the machine shop equipment, the motor capacity usually being 15 hp. All mills are provided with a small cut-off wood saw driven by a 5-hp. motor for sawing up the lumber used for car blocking in the loading of the stone. A mill equipped in this manner will have on the average a connected load of 650 hp. including cranes and a 60-kw. lighting load. The transformers and distribution boards are located near the load centers and are so designed that the larger feeder circuits are kept to a minimum length. All transformers are installed and maintained by the power company and are provided with pole-type primary oil switches for protection against overload and oil disconnecting switches. These are also arranged for manual operation from the ground by means of ropes. The main distribution is made through an all enclosed safety-type switchboard which is equipped with standard safety switches, each feeder being provided with an individual switch and fuse. The wiring throughout the mill is carried in overhead conduits attached to, or hung from, the steel roof trusses or other parts of the frame structure in accordance with the National Electrical Code Standards.

The overhead lighting system is provided throughout the entire mill with R.L.M. dome-type reflectors. All individual drop lights are thus eliminated. The distribution is 110-120 volt, 3-wire. The mill load-factor usually averages about 50 per cent. The plant power-factor is as a rule low, averaging about 70 per cent, although at several of the plants a large amount of synchronous equipment has been installed and this has in some cases resulted in a monthly rebate on the power bills.

In conclusion, it may be interesting to state that the Indiana Limestone Company owns and operates 14 saw mills and 24 cut stone plants in the Indiana Limestone District and that these have a capacity for producing nearly six million cubic feet of sawed stone and up to four million cubic feet of cut stone.

When the Company realized what a saving would be affected by doing away with their own power plants and purchasing power they entered into a contract with the Interstate Public Service Company to supply all the required power. As the Company's requirements were large a very favorable rate was secured. The remaining quarrying machinery which for a while longer will be steam driven, along with the coal required for heating the stone mills, shops and offices, etc., will take approximately 30,000 tons of coal per year, but this amount will be gradually reduced as the electrification is completed.

The increased use of steel and electric power have been large factors in bringing the quarrying industry to its present highly developed state and by no other means could the economies in the labor cost of production have been brought to their present satisfactory state. It is worthy to note that in this, as in other instances, the high cost of labor in America has proved a blessing in disguise as it led to the electrification and modernization of a large industry, that forms such a really important if not vital factor in the building business of the nation.

Arc Welding in the Brainerd Shops of the Northern Pacific Railway Company

Automatic Welding Applied to Building Up Wheel Centers and Guides—Equipment—Operation—Time Required

By G. H. GJERTSEN

Master Welder, Northern Pacific Railway

IN December, 1924, the first automatic welding equipment for the purpose of building up locomotive and trailer-wheel centers was tried out in the Mississippi Street shops of the Northern Pacific Railway Company. In 1925 this set was shipped to Livingston (Mont.) for further tests. The results of these tests led to the installation of similar equipment at the shops at Brainerd (Minn.), South Tacoma (Wash.), and Livingston (Mont.); and the following instructions were issued by the Railway Company:

"All locomotives going through 'Back Shops' must have the driving-wheel centers and trailer-wheel centers carefully checked for the following conditions, subject to repairs by the welding process:

"When the outside diameters of wheel centers are undersize to the extent that shimming is necessary in the application of a tire that is bored to standard size, the wheel center must be built up by the automatic welding process and turned to standard size."

After a locomotive driving wheel has been in service for some time, the wheel center upon which the tire is shrunk becomes out of round or oval shape for several reasons, the principal ones being that the spokes upset and that there are different masses of metal in the wheel; *e.g.*, the counter-weighted portion opposite the crank pin.

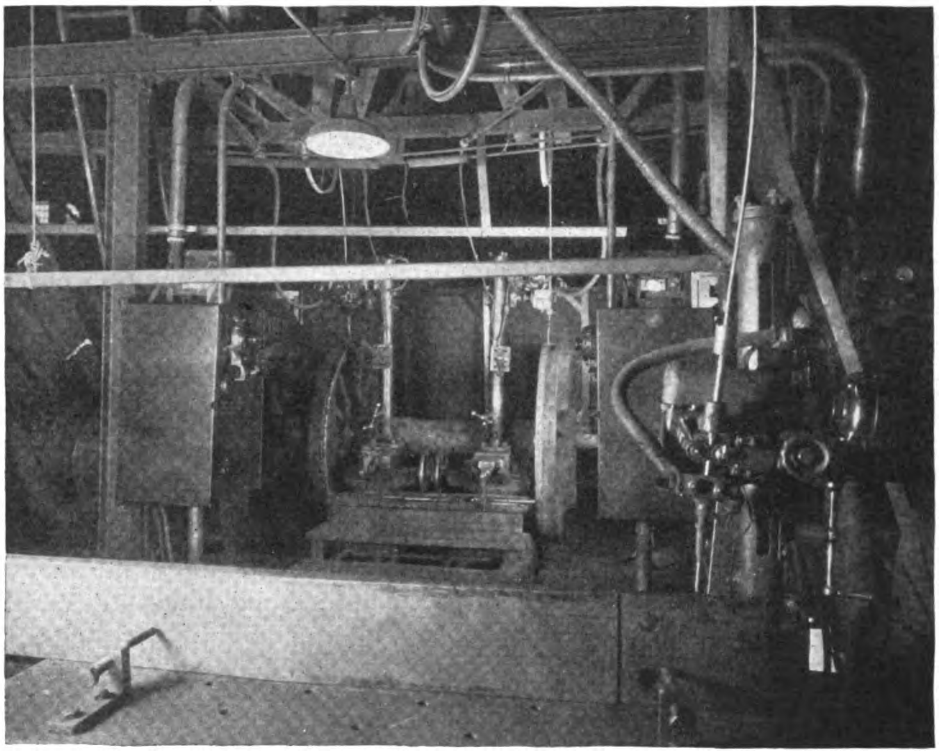

Fig. 1. Automatic Welding Head in Foreground Ready to Build Up a Worn Locomotive Guide. In the Background, a Pair of Wheel Centers Being Built Up by Two Welding Heads

Prior to the application of the welding process to building up wheel centers, it was necessary either to shim the wheel in an attempt to make it round again or else to put the wheel in a lathe and turn the rim down until the wheel was round once more. The first process required shims all the way around the circumference of the wheel, and provided no accurate means of truing up the wheel or allowing for the proper amount of shrinkage of the tire, when it was again shrunk on the wheel.

The second method—that of turning down the wheel centers—required a stock of tires of off-standard bore, which practice was of course very unsatisfactory.

The Northern Pacific Railway Company developed a plan for building up these oval-shaped wheel centers by mounting them in a special lathe and depositing metal on their peripheries by the arc welding process until they were again round, then machining them to their original diameters in a turning lathe, thus making it possible either to remount the tires that had been removed from that pair of wheels or to use other tires of standard bore.

The welding process has proved so economical and so satisfactory in all respects that, in the last three years, the Railway Company has built up 1369 pairs of locomotive driving-wheel centers, 88 pairs of trailer-wheel centers, and 1392 guides in the three shops mentioned.

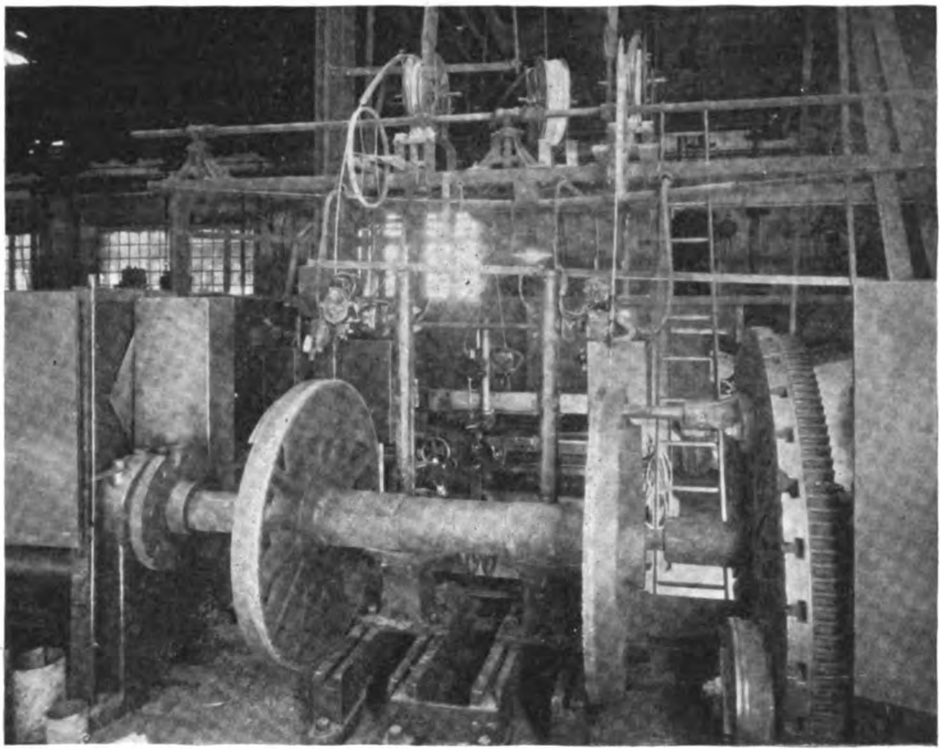

Fig. 2. Another View of the Repair Shop Set-up Illustrated in Fig. 1

In the beginning, use was made of standard individual-operator arc-welding sets with automatic heads operating at about 240 amp. It was soon found that these sets were too small for this work and those in the Brainerd Shops were replaced by a 1500-amp. (intermittent), 1200-amp. (continuous), constant-potential arc-welding set, equipped with three 500-amp. automatic welding heads. Two of these heads are used for rebuilding the wheel centers and the third is utilized for the work on the guides and any other work that can be done by an automatic welder.

Fig. 1 shows the arrangement of the automatic heads in the screened portion of the shop, where the work is done. In the immediate foreground is the automatic head used for building up guides. This is done in an old lathe that has been rebuilt for this purpose. The automatic head is mounted on a carrier on the carriage of the lathe, and can be raised or lowered on this carrier to suit the work. The guide is clamped on a table plate, as shown, and the lathe carriage feed is used to feed the automatic welding head along the guide as the weld is laid on. When the end of the guide is reached, it is necessary for the operator to move the carriage across the guide far enough for another welding bead to be laid on, and to reverse the carriage for the return travel.

In the background of the photograph is shown the two automatic welding heads used for the wheel rebuilding process. The pair of wheels is mounted in an old turning lathe that has been rebuilt for this purpose. The automatic welding heads are mounted on specially constructed carriers, which are bolted to the tool posts of the lathe, these carriers being so constructed that the welding heads can be raised or lowered as required for the different sizes of wheels.

In front of the lathe can be seen the steps and platform upon which the operator stands, and the handles for raising and lowering and for the horizontal movement of the carriers upon which the welding heads are mounted, also the reversing switches for the feed motors on the welding heads. The welding wire is fed from spools mounted on the overhead framework. The lower portion of these spools can be seen at the extreme top of Fig. 1. The entire spools and their mounting arrangement is shown clearly in Fig. 2.

This photograph, Fig. 2, was taken from the rear of the wheel lathe. In the foreground is a pair of wheel centers with a portion of their peripheries already built up, and the welding heads and welding wire in position to continue the building-up process. These wheel centers are revolved at the speed that will produce the surface speed which gives the best results for the thickness of deposit required. This surface speed may be varied from 6 to 12 in. per min., but it has been found that 9 in. per min. gives the best results. The lower the surface speed, the greater will be the thickness of the metal deposited; *i.e.*, if the speed is 6 in. per min. the deposited metal will be approximately twice that which would be deposited were the speed 12 in. per min.

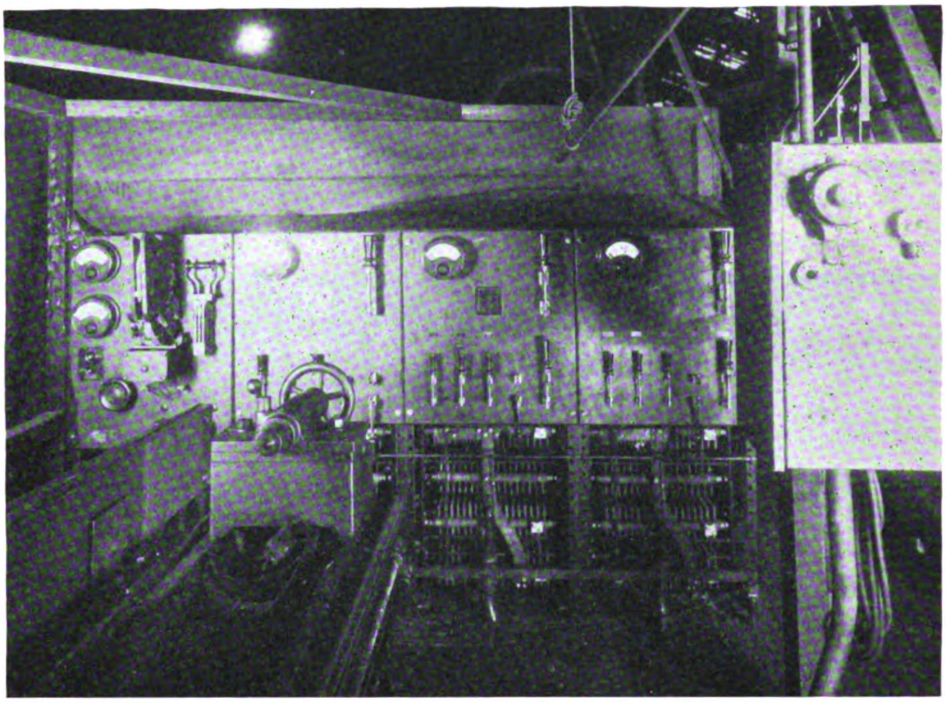

Fig. 3. Generator Control Panel (at the left), Three Circuit-control Panels, and Automatic Control Panel (on post)

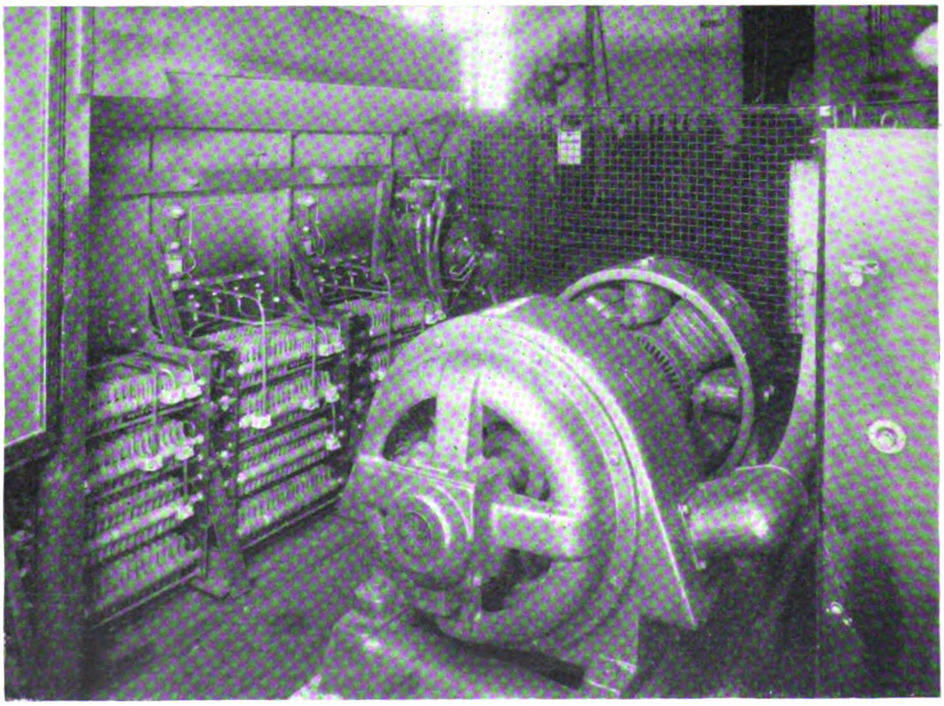

Fig. 4. Welding Motor-generator Set, Its Starting Compensator, and the Rear of the D-c. Switchboard

A deposit of $\frac{3}{16}$ to $\frac{1}{4}$ in. is sufficient to true up the average wheel. The welding wire used is $\frac{1}{4}$ in. and requires 400 amp. with approximately 20 volts across the arc.

The time required to build up a pair of wheels is dependent upon the thickness of metal deposited. Depositing a layer of $\frac{3}{16}$ to $\frac{1}{4}$ in. on a pair of 62-in. wheels will require five to six hours, plus any retouching by hand that may be required. From 38 to 40 lb. is the average amount of welding wire used per wheel.

There are two types of driving-wheel centers in use. One of these has a full face on the periphery and the other has recessed or hollowed-out sections in the center with occasional bridges across.

With the first type, the entire face is built up with the automatic head. In the second case, the outside surfaces of the face of the wheel are first built up with the automatic head and then the bridges are filled by hand operation.

About 25 kw-hr. is required per head per hour of use, so that when both wheel heads and the guide head are in operation the motor-generator set must deliver 1200 amp. at 60 volts, or about 75 kw.

By using a constant-potential 60-volt set, it is necessary to reduce the voltage through resistance banks so that the potential across the arc is approximately 20 volts at 400 amp. This constant-potential set, however, permits the use of a 60-volt motor on the automatic head.

Fig. 3 shows a view of the switchboard control panels. The panel at the left is the main generator panel with the circuit breaker, line switch, field rheostat, and generator voltmeter and ammeter; the other three panels are the welding-circuit control panels with ammeters to show the current drawn in each circuit. At the right, mounted on the steel column, can be seen the automatic control panel.

Fig. 4 shows a view of the motor-generator set, with the 2300-volt motor-starting compensator in the right foreground, and in the left background the rear of the switchboard which was shown in Fig. 3.

The motor-generator set is driven by a 135-hp. 1200-r.p.m. 2300-volt 3-phase 60-cycle motor, direct connected to and mounted on a common base with a 1500-amp. (intermittent) 1200-amp. (continuous) 60-volt constant-potential direct-current generator.

Fan Incorporated in New Electric Air Drawing Ovens

A new air drawing oven, for drawing carbon steel at temperatures up to 750 deg. F. improves quality and increases production as the result of the use of a fan for agitating the air around the work.

Any temperature up to 750 deg. F. can be obtained in the oven, thus covering the full range of temperatures required for drawing and bluing carbon steel. Only 0.9 kilowatts is required to maintain a temperature of 500 deg. F. in the oven; and where the oven is in daily use, but 25 minutes is required to reach a temperature of 500 deg. F. in the morning. By installing a time switch, however, the oven can be brought up automatically to temperature before the workmen arrive, and can be cut off automatically at closing time.

The fan, located in the heating chamber, is driven by a vertical motor mounted on top of the oven. Much less time is needed to heat a given charge when moving air is supplied than would be required by a "still-air" type of oven.

The oven is of double-wall construction throughout, with the intervening space (four inches) filled with high-grade heat-insulating material. The steel sheets which form the walls are electrically welded together and reënforced by angles welded along the corners and extended downward to form the legs. The heating chamber is closed by a well-insulated and closely-fitted door. A strip-steel grate for supporting the work forms the hearth, which is level with the inner edge of the door opening.

One sheath-wire heating unit is located at the top of the heating chamber, and a second is placed just under the hearth. Both windings are so distributed as to obtain uniform heating over the entire hearth. The unit terminals are brought through the back wall to a connection box and are wired to the enclosed control panel.

Temperature control is fully automatic, consisting of an enclosed contactor panel and a controller. The controller can be set at any point up to 750 deg. F. and will hold the oven at a uniform temperature within a margin of five degrees without further attention on the part of the workman. The heat-sensitive device located in the oven chamber governs the operation of the controller, and the latter actuates the contactor through a relay, opening or closing the unit circuit as the temperature of the oven tends to rise above or to fall below the setting. A recorder controller may be used with the oven for obtaining continuous temperature records.

The width of the oven chamber is 24 in., the depth is 21 in., and the height is 9 in. The outside over-all width is 40 in., the outside over-all height is 61 in. and the outside over-all length is 33½ in. The door opening is 24 inches wide and 12 in. high. The hearth is 31 in. above the floor. The normal rating of the oven is five kilowatts, and its heating capacity is 100 lb. of steel per hr. to 500 deg. F.

Electric Welding Pipe-line Field Joints

Equipment—Procedure—Operators—Quality of Work—Data of Cost and Speed of Welding the Joints

By R. W. VAN KIRK

Industrial Department, Dallas Office, General Electric Company,

> *The information presented in this article was obtained from a study of the methods used by successful welding contractors in the electric welding of approximately 1250 miles of gas and oil pipe lines. The outstanding results obtained by electric welding are a positive proof that, when the work is done properly, this method is the best for making field joints.*—EDITOR

THE metallic electrode for welding the commercial grades of iron and steel pipe should be a high grade of carbon steel wire that has a carbon content of 0.20 per cent or less. With the proper electrode and procedure, electric-welded field joints are being made which are stronger than the pipe itself. The wire should be cut into lengths of 14 to 18 in. for convenience in handling.

Commercial thickness of pipe 6 to 20 in. in diameter will require two beads, using generally $\frac{5}{32}$-in. diameter electrode on the first bead and $\frac{3}{16}$-in. to $\frac{1}{4}$-in. on the second. The skill of the operator will be a factor in determining the proper size of electrode.

Welding Current

For the first bead with $\frac{5}{32}$-in. electrode, the welding current will range from 140 to 170 amp.; and for the second bead with $\frac{3}{16}$-in. to $\frac{1}{4}$-in. electrode, from 160 to 200 amp. In general, the greater diameters and thicknesses of pipe will require the higher currents. The skill of the operator will to some extent determine the current used, the higher currents requiring the greater skill.

Source of Welding Current Supply

Single-operator welding machines are available, consisting of a variable-voltage type of welding generator direct-connected to a gasoline engine. The primary factors that determine the choice of the most suitable machine are: sufficient current capacity for continuous hand welding; arc stability for ease in welding; light weight to facilitate transportation along the line; and sturdy construction to withstand rough handling in service.

Figs. 1, 2, and 3 illustrate typical field joints. It is common practice to reinforce the weld approximately 20 per cent, *i.e.*, the thickness of the weld throat should be about 20 per cent greater than the thickness (T) of the pipe.

Welding Procedure

The welding crew is preceded by the lining-up crew which aligns the pipe in long, straight sections on wooden skids, using metal shoes with rollers. The use of the shoes is optional but their use will so increase the speed and quality of weld as to amply repay the contractor or pipe-line company for their cost. The length of the long sections will be determined by the topography of the ground being traversed, the diameter of the pipes, and the machinery available for handling them after they have been welded. In general, they may be from 200 to 300 ft. in length.

For one crew, a convenient number of welding machines is 12, consisting of 4 for making the first bead, 6 for the second bead, and two for the tie-in welds. They should be distributed two machines to a long section both mounted as a unit on one wagon or other suitable means of transportation. Each machine should be provided with a 175-ft. extension and a 50-ft. return cable. They should be located at the middle of the long section and not moved until their assignment for that section has been completed. For moving them, one caterpillar tractor is found sufficient to handle a crew of twelve.

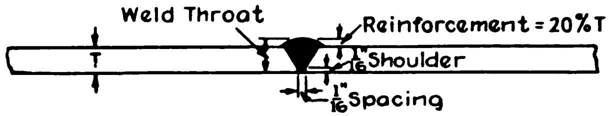

Fig. 1. Sectional Sketch of Butt Weld

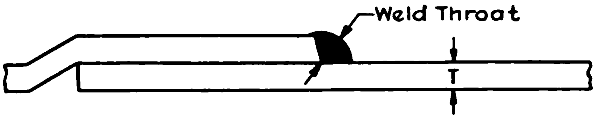

Fig. 2. Lap Weld on Bell and Spigot Joint

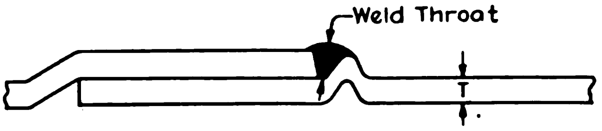

Fig. 3. Lap Weld with Welding Dam on Spigot End

In laying the first bead the operator should begin at about the side center of the pipe and weld to the top center, taking care to penetrate thoroughly. He should then move over to the other side of the pipe and weld upward, meeting the initial bead at the top, following which he should proceed to the next joint. While he is welding on this joint the helper should clean the scale thoroughly from the previous bead, using a hammer chisel and wire brush, chipping the beginning and end of the bead especially clean.

When both operators have completed all the joints in their section one-half the way around, the pipe is to be turned over and all the first beads completed. After all beads have been cleaned, the operator and equipment are ready to be moved to the next section.

The second bead should be started at one side, welding toward the top. The first bead makes the joints amply strong so that the pipe may be turned while welding, thus permitting the laying of a continuous second bead. When completing the weld it should be continued on to the beginning of the bead and then curved slightly, ending on the pipe. Peening the end of the weld is not desirable. It is not considered necessary and might be done in such a manner as to injure the weld.

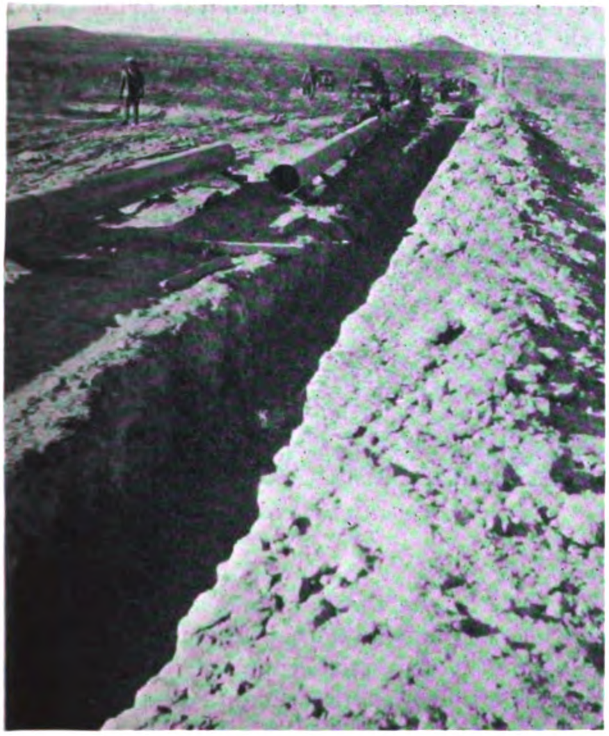

Fig. 4. The Ditch with Sections of Pipe Alongside

After the completion of the second beads, the long sections are ready to be lined up on skids over the ditch. The tie-in welding machines are mounted in single-operating units, as the tie-in welds are several hundred feet apart. In welding these joints the pipe cannot be turned. As a result, part of the weld must be made overhead and thus a welder experienced in this type of work is required. When the tie-in welds have been finished, the pipe is a continuous tube ready to be lowered into the ditch.

Qualifying Operators

The tests for determining the ability of operators must be made with materials and testing tools readily available in the field. The welding should be done under field conditions and should conform to the specifications. A section of standard butt-weld pipe can be cut in short sections about six or eight inches long and machined to the standard bevel in a local machine shop. One 20 or 30-ft. section will provide a large number of test joints. This same test will serve for bell and spigot joints, although if desired alternate six or eight-inch lengths can be cut through at one side and spread open to form the bell.

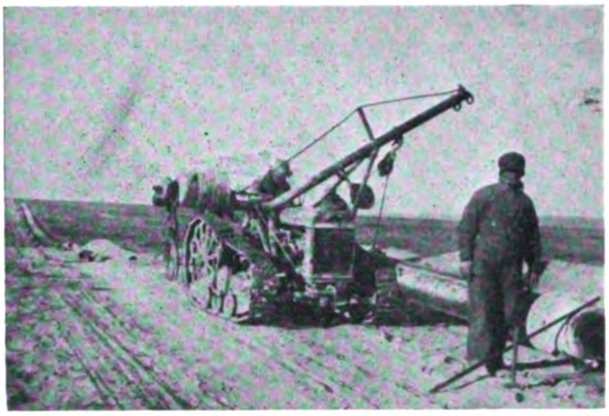

Fig. 5. Lining Up the Pipe Preparatory to Welding

The welding inspector and supervisor are jointly responsible for the work and should combine in conducting the qualification tests. They should adjust the current to the average value with which the operator will be expected to work. The test welding should be watched closely for

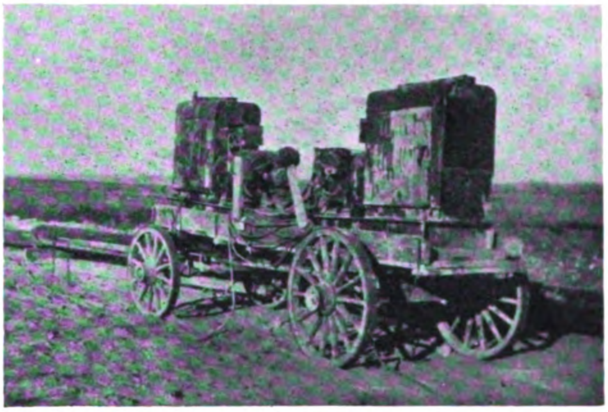

Fig. 6. Two Welding Machines Mounted on a Wagon for Welding the Pipe Lengths in a Section

(*a*). The holding of a short arc
(*b*). Thorough penetration
(*c*). Regular steady movement of the electrode.

When the test weld is completed, several specimens 1 to 2 in. wide should be cut from it. These may be placed on a "V" block or in a vise and held so that, using a sledge, the coupon may be bent double with the bend coming directly at the weld. Usually it will not be possible to break a weld made by an experienced operator; however, if a fracture in the weld is obtained it should be inspected closely for penetration and for proper appearance of the deposited metal.

If the test weld fractures, it should at least have resisted stubbornly and tear away irregularly. The weld metal should be dull gray with a close, even texture and fibrous appearing structure. There should be no blowholes, slag inclusions, and brown or blue-colored metal.

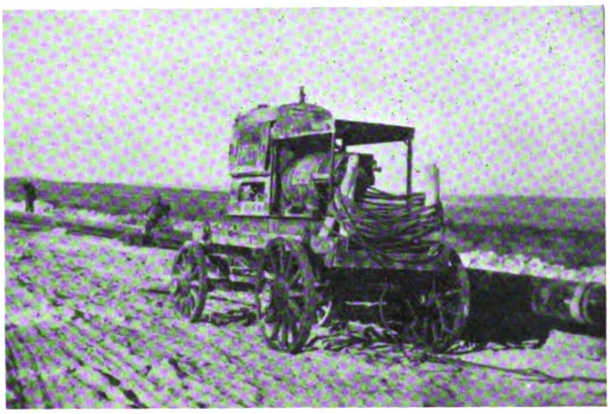

Fig. 7. Single-unit Welding Outfit for Tying-in a Section

Inspection

The first duty of an inspector is to insure the proper preparation of the joints. Commercial pipe is usually covered with a rust-resisting coating which should be thoroughly removed. The next step is to insist that the pipe sections be lined up as straight as possible. A poor line-up will result in a joint touching on one side and a wide gap on the other. In the ditch such a joint will be subject to localized stresses and these will seriously affect its over-all strength.

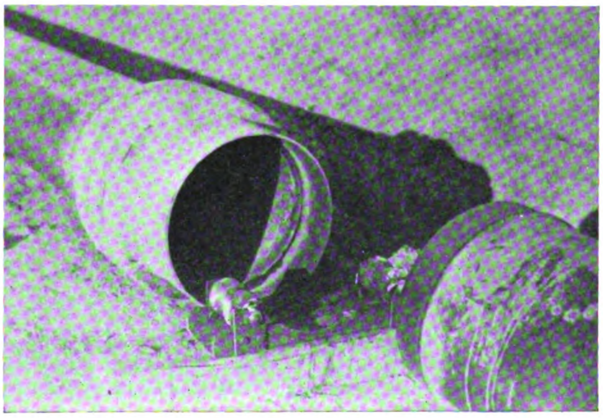

Fig. 8. Typical Expansion Joint and Bell End, and Spigot End with Upset Ring or Welding Dam, Ready to be Placed on the Rollers of the Metal Shoe and Wooden Skid

The other duties of the inspector are: to determine the size of the beads, fusion, and quality of the deposited metal. Inspecting the size of the beads is a mechanical operation requiring no particular skill.

Quality of the Deposited Metal

The weld metal should be smoothly laid and should have a clean steel blue color. A smooth neat appearing bead is not a requirement of a successful weld, nevertheless it is an indication of the operators' steadiness in manipulating the electrode. If the metal looks burned in places a test coupon should be cut out, carefully examined and tested by bending or be given a tensile strength test.

The weld should be examined closely for minute pinholes indicating porosity and sponginess. This may be caused by low current or too rapid welding speed.

If the weld rusts while cooling it is an indication that too long an arc was held. This results in the absorption of oxygen and nitrogen, both of which are detrimental to the quality of the weld. With a short arc, the flame consisting of vapors coming out of the arc acts as a protection and largely prevents the absorption of outside gases. One or more test coupons should be cut out of such a joint.

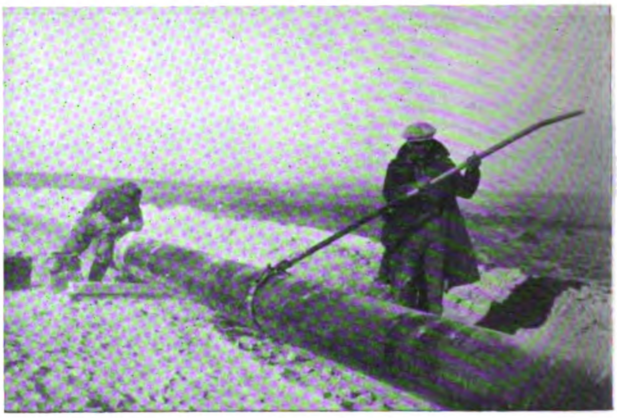

Fig. 9. A Welder at Work and a Man with Tongs Turning the Pipe

Fusion

The first requirement for fusion is that the bead must make a smooth fillet where it joins the pipe. It must not overlap, *i.e.*, seem to roll over on the pipe, but should be a continuation of the pipe metal. A common test is to place a knife blade at the edge of the bead. If it can be inserted at all under the edge of the weld metal, improper fusion has resulted.

At the point where the arc strikes the pipe the pipe metal is melted and is forced out of the molten pool by the arc. This depression is called the crater and will be found at the point where the weld was finished. The crater can also be noted while welding, and when the operator is changing electrodes. Its depth and general shape provide a means of judging the penetration and fusion, and of predicting the soundness of the weld. Its depth in general should be at least $\frac{1}{16}$ in.

The crater should be neat and circular in shape. If it is small, relative to the size of the bead, the welding current should be increased; while a large elongated crater would indicate too much current.

If a reliable, uniform, welding electrode is being used with the proper current and a spattering of large globules of metal is found near the weld, it indicates a long arc. Such joints should be examined carefully and the faulty operator watched closely.

The sound of the arc is also a good criterion of the quality of the work. An experienced inspector can pass on a weld with surprising accuracy by listening to the sound produced by the arc. A good weld on clean material with the proper current and a short steady arc is indicated by a rapid, sharp, sputtering and crackling sound. A long arc will be accompanied by a hissing sound. An unsteady arc will result in intermittent crackling, hissing, and breaking of the arc. This same result will also be obtained with an improperly cleaned joint.

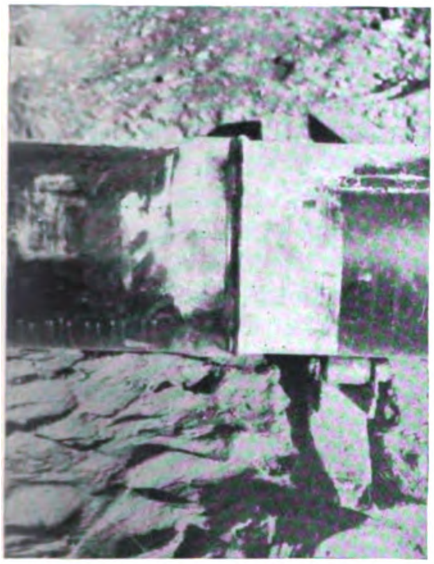

Fig. 10. Joint Tacked, Ready for Welding

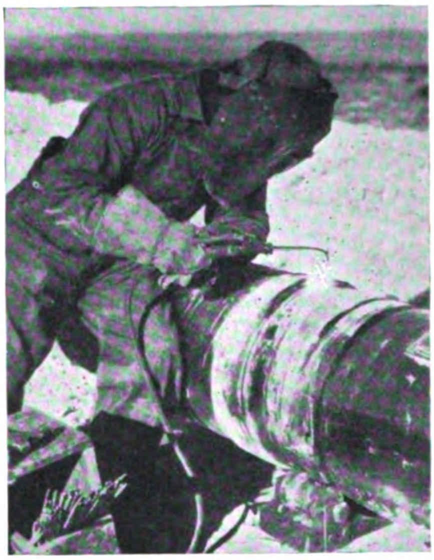

Fig. 11. Welding the Sections

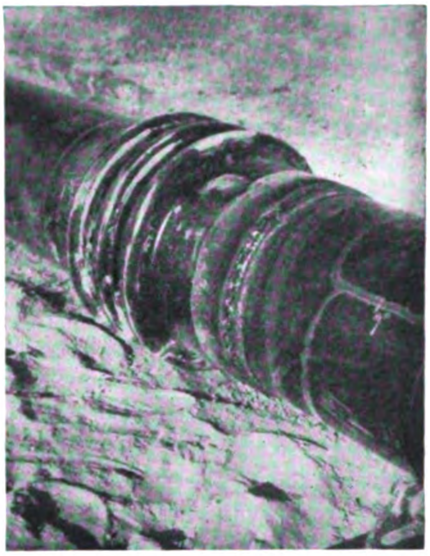

Fig. 12. Completed Expansion Joint

The voltmeter and ammeter, furnished as standard equipment on welding machines, also provide excellent means for indicating the steadiness and length of the arc. With the currents and electrode sizes in use on pipe-line work, the arc voltage should hover closely at 20 volts. The ammeter will generally fluctuate through a comparatively much wider range. It performs a very necessary service however in indicating the current. The value of current used is found to very materially effect the quality of the welds; and one of an inspector's most important duties is the determination of the proper current.

Cutting Out Inspection Coupons

For the mutual protection of both the pipe-line company and the welding contractor, test coupons should occasionally be cut at random from welds made by each operator as well as from all doubtful welds. The knowledge that any of his welds may be given such a detailed inspection will serve to make the operator careful.

These coupons may be obtained with a cutting torch or a milling machine. In cutting them out, care should be taken that they are not damaged in any way so that they will be a reliable indication of the quality of the weld. They can be tagged and shipped for full laboratory examination.

Number of Welds per Day and Cost Data

Table I furnishes data of the results obtained by contractors when electric welding pipe lines by the general procedure that has been described in this article. The data are based on the use of the butt or bell and spigot joints which call for welds as illustrated in Figs. 1 and 2. With the bell and spigot joint, manufactured with a welding dam on the spigot end, the number of welds per day will be increased approximately 25 per cent.

TABLE I

ELECTRIC WELDING OF BUTT OR BELL AND SPIGOT JOINTS

Continuous Operation

PIPE DIAMETER		6 In.	8 In.	10 In.	12 In.	14 In.	16 In.	20 In.
Number of joints per machine in 10 hr.		30	24	19	15	11	8	6
	Pipe Lengths							
Number of welding machines required for 1 mile per day	20 ft.	9	12	15	18	24	33	45
	30 ft.	6	8	10	12	16	22	30
	40 ft.	5	6	8	9	12	17	23
Pounds rod per weld		1.4	1.8	2.2	2.8	3.6	4.6	6
Cost rod per weld		$0.119	$0.152	$0.187	$0.238	$0.306	$0.391	$0.510
Gallons gasoline per weld		0.4	0.6	0.8	1.0	1.4	2.1	3.0
Cost gasoline and oil per weld		$0.077	$0.110	$0.146	$0.183	$0.255	$0.372	$0.533
Total cost gasoline, oil and rod per weld		$0.196	$0.263	$0.333	$0.421	$0.561	$0.763	$1.043

The Lightning Arrester and Factors Affecting Its Performance and Application

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> *New facts are constantly being revealed concerning voltage surges and the devices used for protection against them. This article tells of the action of arresters under different conditions of service; location, grounding, and values of circuit constants; and of the degree of protection afforded in the various cases. It was originally presented as a paper before the regional meeting of the N.E.L.A. at Louisville (Ky.), on May 8, 1929.*
> —EDITOR

THE application of lightning arresters and the analysis of their performance on any electric system involve essentially a consideration of the voltage conditions of the system. The lightning arrester is fundamentally a voltage device and, properly designed, operates independently of the transmitted current, power, size, or number of the generators supplying the system.

The voltages which must be considered are: first, the normal operating system voltage; second, the abnormal maximum system voltage; third, the surge voltages from normal and abnormal operating conditions such as switching and arcing grounds; and fourth, the lightning voltages induced on the exposed circuits. The first two voltage considerations govern the design of the arrester, the purpose of which is to limit the magnitude of the latter two classes of voltages.

While the rating of lightning arresters is based on the so-called standard system ratings, the arrester rating should at least be equal to the highest sustained line-to-line operating voltage of the circuit which might exist for any period, caused individually or collectively by high taps on transformers, over-excitation of generators, maximum boost by regulators, or light-load operation.

The design of the arrester based on the maximum sustained operating voltage alone is unwise and the abnormal system voltage conditions must be considered to prevent the arrester from failing when these abnormal system voltages occur. Experience has shown that the abnormal system voltages are not generally serious on the lower and medium-voltage distribution systems; so that, in general, the distribution types of arresters do not require the factor of safety in valve or sealing characteristics that is required of arresters for the higher transmission voltages. Loss of load and the attending over-speed of generators on transmission systems is a dominant factor in the design of arresters for these systems. The value of excess or runaway voltage depends upon the system set-up and resultant overall regulation, and largely upon the speed-voltage characteristics of the generators. Studies of the latter have shown that steam-driven machines may produce 50 per cent rise, and hydraulic machines 100 per cent rise above normal rated voltage, the worst condition being encountered with direct-connected exciters. Although these excess generator voltages exist for only a few seconds, while the governors and voltage regulators are coming into action, the duration is entirely sufficient to destroy lightning arresters which discharge during this period of excess voltage. It has frequently been suggested that the spark-over voltage of the arrester gap be increased to a value above the maximum possible runaway voltage as a means of keeping this excess voltage off the arrester element; but this measure cannot be relied upon, owing to the possible presence of transient surges with magnitudes of several times normal voltage which would still spark over the arrester gap. It is therefore necessary for the arrester to be capable of preventing the flow of system current attending these extreme system voltages through it, or to successfully interrupt the flow of such current without damage. Since the relief voltage and protective characteristic of most arresters are directly proportional to the 60-cycle sealing or valve voltage, it is obvious that protection is sacrificed by whatever percentage of factor of safety must be introduced in the arrester to withstand the excess system voltages.

A preferable corrective measure is to limit the magnitude of the runaway voltages by the introduction of over-voltage or over-frequency control on the generators. Careful investigations evidence that it should be possible to limit the runaway voltage of generators to a maximum of 25 or 30 per cent above normal and do this with sufficiently positive performance to justify the design of arresters for only slightly above the voltage as limited by this means. It will be obvious, particularly to those operating engineers who are placing increasing dependence upon arresters, that so limiting the maximum system voltage is far more rational than accepting 50 or 100 per cent possible excess of normal voltage, which acceptance demands that all of the arresters for the system cost more and give less protection. The cost of the means of limiting the over-voltage of the generators would be saved in the cost of a very few arresters; and while the major benefit would be in improved protection at less cost, the elimination of the extreme runaway voltages from all apparatus is desirable.

Often one circuit may be exposed to an excess 60-cycle voltage by induction from a higher-voltage circuit, making it necessary to consider the induced voltage in applying arresters. In one instance, a 550-volt circuit closely paralleled a 120-kv. line and short circuits on the latter caused a potential of about 2000 volts to be induced on the 550-volt circuit for the duration of the short circuit. This induced voltage was a 60-cycle voltage sustained for a matter of seconds and necessitated arresters having a valve element designed for 2000 volts instead of for the normal 550-volt rating of the circuit.

The third class of voltages involving switching and arcing-ground surges are probably different for every system. Some studies by means of surge recorders during the past three years indicate that the majority of switching surges are less than three times normal, normal being the crest value of the line-to-neutral system voltage. Switching loads on and off seems to produce relatively mild surges, while energizing and deënergizing unloaded lines produce a worse condition. The majority of data has perhaps been obtained on the higher-voltage systems; and six or seven times normal represents the order of the highest switching surges, this magnitude occurring with the deënergizing of an unloaded line. About 50 per cent of the switching surges seem to be around three times normal. Of the surges of greater magnitude, only about five per cent reach four and five times normal. These switching surges result from readjustments of the stored electrostatic and electromagnetic energy in the system. The character of the switching surges varies through wide limits; but, in general, the time element and energy of the surge will impose no hardship on arresters of ordinary design. The wave fronts of these surges are usually slower than the transients due to lightning.

The arcing-ground surges will of course occur only on those systems operating with delta-connected or ungrounded neutral. Unlike the switching surge, the arcing-ground surges are recurrent as long as the ground fault exists. According to W. W. Lewis, the maximum voltage theoretically obtained from arcing grounds is about six times normal. Values slightly in excess of this have been shown from surge recorder studies. These arcing-ground surges are a damped oscillation superimposed on the 60-cycle or system voltage and will cause continuous discharge of arresters on the two ungrounded phases for the duration of the ground fault. The energy of the surges depends on the character and constants of the system. While the energy in any group of ocsillations is small, the more or less continuous discharge of these surges through arresters tends to exceed the heat storage capacity of arresters and the arcing ground is unquestionably the most probable cause of arrester troubles.

The lightning voltages to which arresters may be subjected may be of any magnitude up to the flashover of the line insulation. This flashover limit is fairly definite for lines with steel towers or grounded hardware and less definite for the case of wood poles and cross arms in series with the line insulation. Wood greatly increases the lightning flashover of a line and this increase is about the same for dry, wet, creosoted, or untreated poles. Peek(1) has given a figure of 180 kv. per ft. for wood flashover. While the insulation or over-insulation of lines is quite variable, those lines of 66 kv. and above, which usually have steel towers, are generally insulated so that the r.m.s. 60-cycle dry flashover averages about 3.8 times the system rating or 6.5 times the system line-to-neutral voltage. The lightning flashover of the insulation, based on a fairly steep wave, will approximate 10 to 12 times the crest value of the line-to-neutral voltage of the system. For systems with wood poles and ungrounded hardware, the lightning voltages from line to ground will not be limited to 10 or 12 times normal but may rise to very much higher values. Because distribution circuits frequently have the same elevation above ground as the much higher voltage transmission lines, the former may frequently have lightning voltages approaching those on the latter, particularly if they have wood poles and cross arms. Therefore, when expressed in multiples of the normal value, the low or medium-voltage distribution system may be subject to a much higher lightning voltage than the high-voltage transmission systems. Surge recorder studies on even the higher-voltage systems have shown lightning voltages up to 15 times normal, this magnitude, however, being found infrequently. An alarming percentage of the surges seem to be of a dangerous magnitude, 10 per cent of them having magnitudes from six to ten times normal on some systems of 110 kv. and above. The rate of rise of these voltages induced by lightning is the subject of a great deal of investigation, the work being conducted on several systems during the present lightning season. Last year some data were obtained with the cathode-ray oscillograph evidencing wave fronts of 5 to 10 microseconds. Efforts to deduce the probable wave fronts from surge recorder studies give rise to the suspicion that the great majority of the lightning surges have fronts slower than ten microseconds, with only one surge suggesting a wave front of less than one microsecond. The several field studies with cathode-ray oscillographs this season should provide much dependable information on wave fronts and the general shape of the induced voltages.

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(1) "Progress in Lightning Research in the Field and in the Laboratory," by F. W. Peek, Jr., presented at Winter Convention of A.I.E.E., Jan. 28, 1929.

Some surge recorder studies(2) and also surge investigations on lines with the cathode-ray oscillograph(3) indicate that lightning voltages attenuate fairly rapidly, the attenuation being a constant times the kv. squared (ke_o^2). This attenuation is due chiefly to corona. The constant naturally varies with the size of the conductor, character of insulation, presence and proximity of ground wire, etc., and values from 0.00016 to 0.0008 are found from data at hand. The attenuated voltage is $e = \frac{e_o}{kse_o + 1}$ where s is the distance in miles for the original voltage e_o to attenuate to the voltage e. A figure for the constant k is 0.00016, which is probably conservative in showing less attenuation than might actually occur. For convenience in mental calculations of attenuation, the distance in miles that a wave will travel to attenuate to one-half value is equal to 6250 divided by the original voltage. For instance, a 1000-kv. wave will attenuate to 500 kv. in 6.25 mi. and a 500-kv. wave will attenuate to 250 kv. in 12.5 mi.

Grounded *vs.* Non-grounded Neutral Systems

There does not seem to be any reason for expecting a difference in the severity of lightning voltages occurring on grounded or non-grounded neutral systems. The magnitude of the lightning potentials for either circuit depends upon the exposure of the lines and their elevation above earth, the induced lightning voltages being the product of the change of cloud-to-earth voltage gradient and the height of the line conductors, the time element for the change in gradient being a factor. It would therefore seem that the number of apparatus flashovers or line insulator flashovers should not be affected by grounding the neutral; but the number of times that power current will follow a flashover will naturally be greater with the grounded neutral system.

The switching surges are generally of a lesser magnitude on the grounded-neutral system; and arcing-ground surges are eliminated entirely, thereby removing a source of disturbance hazardous to lightning arresters.

Considering inductive apparatus particularly, there are few or no data showing that the susceptibility to failure by lightning would be different with the Y or delta connection. However, with the inductive windings, delta-connected impulses may enter the windings from both ends.

The solidly grounded neutral system permits special arrester applications giving better protection at somewhat lower cost. The interpretation of the term solidly grounded is that the neutrals of all generating or other sources of power feed shall be permanently and directly connected to a very low resistance ground with no intervening reactors, resistance, fuses, or switches, so that under any condition of system switch operation the arresters can never be supplied by an ungrounded source; and the neutral will be definitely fixed at earth potential. If the neutral is solidly grounded, the special grounded neutral arrester may be applied anywhere on the system regardless of length of transmission or isolation of stations. The grounded neutral arrester will in general give better protection, limiting the lightning stress to about 80 per cent of that with the arrester for non-grounded systems.

Lightning Arresters

The duty on lightning arresters and their response to that duty is the subject of continued investigations; and operating engineers have just reason to expect for the future even greater immunity from lightning failures than now experienced. For several years the cathode-ray oscillograph has made possible in the laboratory exacting studies of arrester protective characteristics, and more recently on actual transmission lines. This, together with the several investigations being conducted this season with cathode-ray oscillographs for determining the magnitude and wave-shape of lightning on actual lines are very definite advances which will continue to stimulate developments and improvements in arresters and their application for maximum benefits.

It is generally conceded that the protective characteristic of an arrester should provide a horizontal or nearly horizontal volt-ampere characteristic in which the voltage across the arrester is nearly independent of the amplitude of discharge current. Dividing the voltage ordinates by the current abscissas indicates that the internal resistance of the arrester must decrease rapidly with increasing current and that the actual resistance of the arrester for any discharge in practice depends upon the amplitude of the discharge current.

The percentage by which an arrester reduces the voltage of a lightning impulse or wave depends on the relation of the arrester resistance plus the ground resistance to the surge impedance of the circuit at the point of installation. This relationship of discharge-path resistance to surge impedance can be plotted and is shown in Figs. 1, 2, and 3 for the cases most common in practice. Fig. 1 is the most common case for an arrester connected from line to ground at a transformer terminal, the transformer being at the end of the line. The surge impedance of the line (Z_1) is assumed to be 500 ohms and that of the transformer (Z_2) assumed to be 5000 ohms. The discharge path resistance in ohms is plotted against the discharge path voltage and current in per cent of the wave voltage and current. It will be seen that if the discharge path resistance is zero the voltage across it is zero and the current through the discharge path is 200 per cent of the wave current, this condition constituting a so-called current reflection which results in a voltage of opposite sign and equal to E_1 being reflected back on the line. If the resistance is 100 ohms, the incoming wave is reduced to 33 per cent and the current through R is 163 per cent of the wave current on the line. The reflected voltage wave of opposite sign will be the difference between 33 per cent and 100 per cent, or a wave of 67 per cent of E_1. If the resistance (R) is 500 ohms, which is equal to the line surge impedance, the voltage across R and the current through R are 95 per cent of the voltage and current on the line. If Z_2 had been infinity, as with an open-ended line, the resistance voltage and current would have been 100 per cent and the wave would be completely absorbed in the resistance. The assumed transformer impedance changes the condition but slightly from the case of an open-ended line. The dotted curve shows the energy absorption from the incoming wave (E_1) for the various values of R.

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(2) "Surge Voltage Investigations on Transmission Lines" by W. W. Lewis, presented at Summer Convention of A.I.E.E., Denver, June 25, 1929.

(3) "Cathode-ray Oscillograph Study of Artificial Lightning Surges on Turners Falls Transmission Line," by K. B. McEachron and V. E. Goodwin, presented at Regional Convention of A.I.E.E., Cincinnati, March 20, 1929.

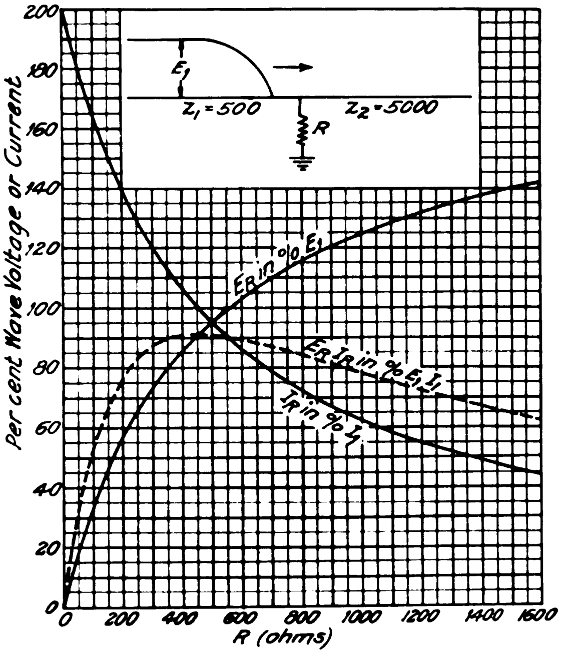

Fig. 1. Current, Voltage, and Power Relations as Functions of Discharge Path Resistance, When Arrester is Located at Junction of Line and High Surge Impedance Such as a Transformer

Fig. 2 is a similar plot but for the case in which the arrester is located along a line where the surge impedances on both sides of the arrester are equal. It is seen that if R is 100 ohms in this case the voltage across R is about 29 per cent of the incoming wave and the current through R is 143 per cent of line current. The difference between 29 per cent and 100 per cent is the portion of the incoming voltage which is reflected of the opposite sign. It is seen that for any value of R the voltage across R is lower than in the preceding case. It is also noted that the maximum absorption in R occurs when R is about 250 ohms and that under this condition only 50 per cent of the incoming wave energy is absorbed.

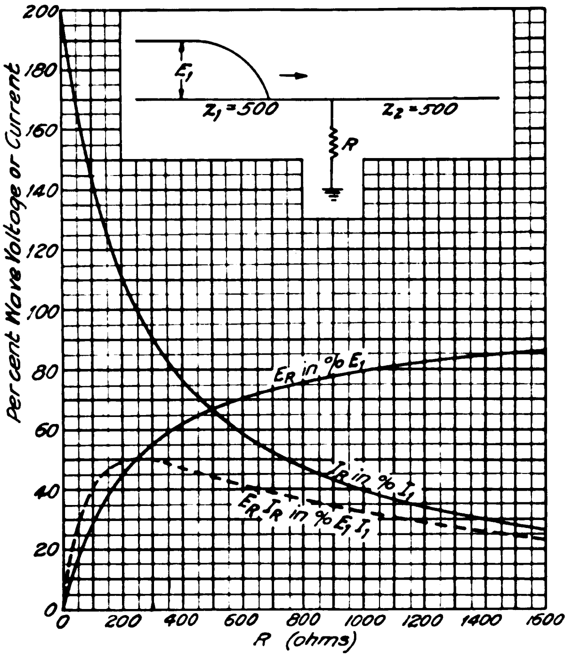

Fig. 2. Current, Voltage, and Power Relations as Functions of Discharge Path Resistance, When Arrester is Located Along the Line

In Fig. 3 we have a similar plot, but for the case of an arrester at the junction of an overhead line and a cable which is long in comparison with the incoming wave, the surge impedance of the cable being assumed as 50 ohms. Here it will be seen that with $R = 100$ ohms the voltage across R is 12.5 per cent of the incoming wave voltage and the current through R is 62 per cent of the line current. For maximum absorption in R the latter must be about 50 ohms; and when this is the case the absorption is only 10 per cent of the incoming wave energy.

There are two desirable accomplishments for arresters: first, and most important, to reduce the voltage of waves at the arrester terminals; and second, but less important, to absorb as much of the wave energy as possible so as to minimize the amplitude of the reflected wave and its energy. That both conditions cannot be obtained is evident. The condition for maximum absorption demands that the arrester resistance be such that the arrester does not appreciably reduce the voltage at its terminals below that dictated by the circuit surge impedances. To limit the voltage at the arrester to such value as would be considered good protection requires an arrester resistance very much smaller than that which permits maximum absorption. The curves indicate that lower-resistance discharge paths are necessary in distribution arresters than are necessary for the higher-voltage arresters. For instance, a 2300-volt distribution circuit might be subject to a lightning voltage of 300 kv.; and if it is desired to limit the stress on a 2300-volt transformer to 15 kv., the voltage across the arrester and ground resistance must be 5 per cent of the wave voltage, thus requiring the discharge path resistance to be of the order of 10 ohms. For the high-voltage system, the line insulation more commonly limits the lightning voltage to around 10 or 15 times the normal line-to-neutral value and the high-voltage arrester does not have to reduce the possible lightning voltage to as low a percentage to give complete protection. For instance, the maximum lightning voltage as limited by the usual 110-kv. insulation would be in the neighborhood of 1100 kv.; and if an arrester reduces this to 400 or 500 kv. the protection is quite satisfactory. To hold the voltage to 40 or 50 per cent permits the arrester resistance to be of the order of 100 to 200 ohms.

Fig. 4 is a cathode-ray oscillogram, taken on a 3-kv. pellet-type arrester, of a fairly steep impulse which produced 800 amp. discharge through the arrester. The horizontal volt-ampere characteristic shows a crest voltage of 6.3 kv. allowed by the arrester. A value of 15 kv. occurred for the instant of gap breakdown, *i.e.*, up to the time that current begins to pass through the arrester. While it would be unquestionably desirable to eliminate this higher gap breakdown voltage, it is believed that the effect of these extremely brief over-voltages are of less significance than the main *IR* characteristic, since the latter may endure for a much longer period. In limiting the voltage to 6.3 kv., which is about 2.1 times the 60-cycle rating of the arrester, the arrester impedance was down to about eight ohms at the maximum discharge current.

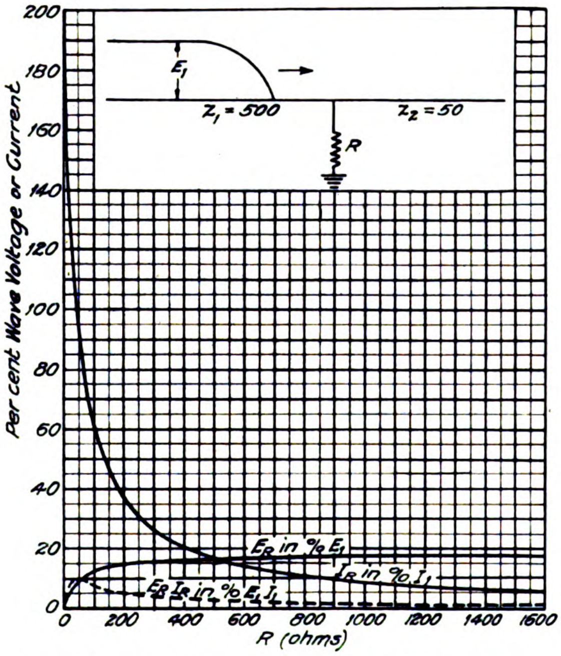

Fig. 3. Current, Voltage, and Power Relations as Functions of Discharge Path Resistance, When Arrester is Located at the Junction of Line and Cable or Other Low Surge Impedance

It must be remembered that the protective characteristic can be greatly altered in practice by the presence of the ground resistance in series with the arrester between line and earth. Fig. 5 is a cathode-ray oscillogram for the same arrester in series with an actual driven ground which had a 60-cycle measured resistance of 55 ohms. It is seen that the volt-ampere characteristic of the combination is no longer horizontal but the voltage increases appreciably with increasing current. It is interesting to note that the impulse resistance of the ground at the maximum current was about 41 ohms, which is somewhat below the 60-cycle measured value of 55 ohms.[4] This order of ground resistance is above that ordinarily recommended in distribution practice, 15 ohms being a desirable maximum.

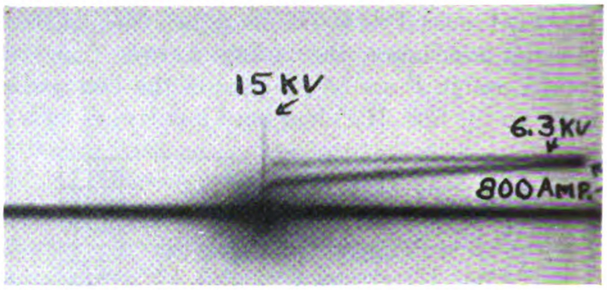

Fig. 4. Cathode-ray Oscillogram, Showing Volt-ampere Characteristic of a 3-kv. Pellet-type Arrester (Fairly Steep Impulse Producing 800-amp. Discharge Current)

From the horizontal volt-ampere characteristic in Fig. 4 it is possible to plot the wave voltage, wave energy, arrester voltage, and arrester energy against the arrester current. Fig. 6 shows these relationships based on the upper or rising part of the volt-ampere characteristic. These curves indicate that a voltage wave of about 130 kv. would cause a 500-amp. discharge through the arrester. The voltage across the arrester is less than 5 per cent of the wave voltage. The energy rate of the wave (E_1 I_1) would be about 32,500 kw. and the energy rate absorbed in the arrester would be about 3200 kw. The arrester kw. in per cent of the wave kw. is thus shown to be about 10 per cent. A wave voltage of 40 kv. would cause about 150 amp.

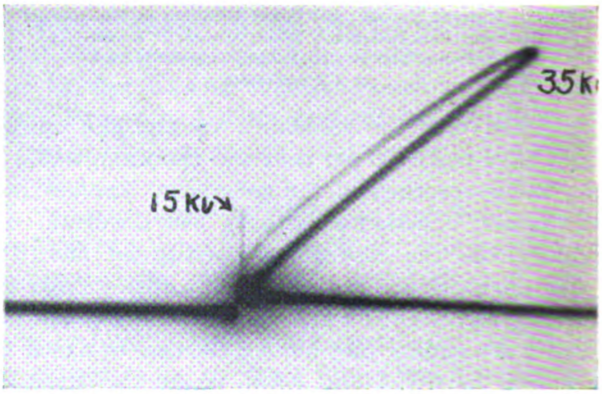

Fig. 5. Cathode-ray Oscillogram, Showing Volt-ampere Characteristic of the 3-kv. Pellet-type Arrester in Series with a 55-ohm Ground Resistance

discharge through the arrester, and the arrester would reduce the voltage to about 15 per cent. The kw. in the arrester would be about 28 per cent of the kw. in the wave.

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[4] "Impulse Characteristics of Driven Grounds," by H. M. Towne. General Electric Review, November, 1928, p. 605.

Conditions more truly representing service performance are shown in Fig. 7, which is similar to Fig. 6 except that 15 ohms ground resistance has been introduced in series with the arrester. A wave of 132 kv. would cause current of 500 amp. to flow through the arrester. It will be seen, however, that owing to the presence of the 15-ohm ground resistance, the kw. rate in the arrester is 20 per cent. A 40-kv. wave would cause about 150 amp. discharge current and the kw. in the arrester is about 36 per cent of the wave kw.

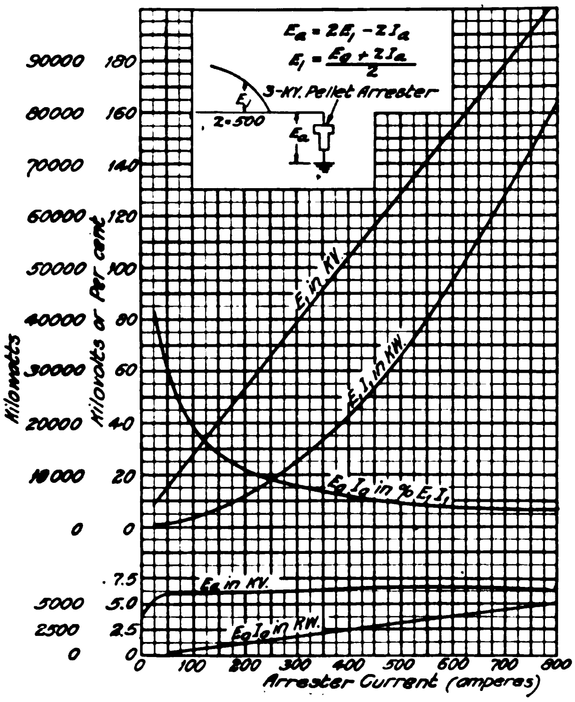

Fig. 6. Kv. and Kw. of Traveling Wave, and Kv. and Kw. of Arrester as Functions of the Arrester Discharge Current. Case of 3-kv. pellet-type arrester located at end of line

If a wave strikes the open end of a line without an arrester, the voltage E reflects to $2E$. Fig. 8 shows the voltage with the arrester in per cent of $2E$ for various values of discharge current with and without the 15-ohm ground resistance.

The actual energy in the wave and that absorbed in the arrester can be stated only after time is known; and for the practical case the energy is in watt-seconds, owing to the extremely short duration of the wave or impulse on the line.

The ground resistance in series with the arrester plays a very important part in the final protective performance, in the amount of absorbed energy, and in the resultant reflected voltage wave and its energy. There seems to be merit in designing for the lowest volt-ampere characteristic in the arrester, thus providing the maximum possible voltage reduction by the arrester. This seems logical from three viewpoints: First, the arrester is generally installed to protect a given piece of apparatus against not only the moderate but the most severe surges of both original and reflected origins. To protect against the severe surges, the arrester voltage must be a very small percentage of the wave voltage; and this requires low internal resistance in the arrester and resulting voltage reflections of opposite sign back onto the line. Second, that any reflected voltage wave, even with the lowest-resistance arresters, will always be less than the incoming wave; and if the latter would not cause line flashover the reflected wave of lesser magnitude will be equally harmless. Third, the difficulty of obtaining low-resistance grounds insures that the majority of installations will have enough resistance in series with the arrester to enable the combination to effect quite an appreciable absorption of the wave energy. Moreover, the lower the resistance of the arrester, the less is the necessary expense for arrester grounds to obtain a given degree of protection.

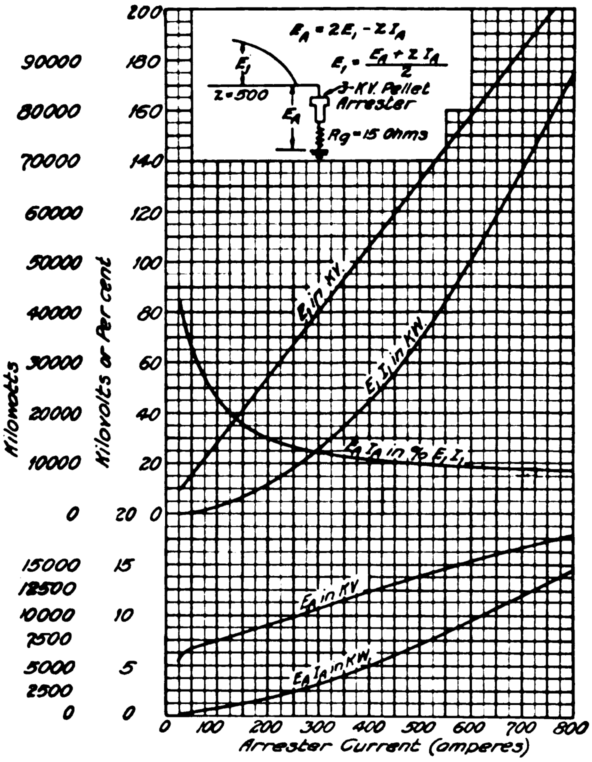

Fig. 7. Kv. and Kw. of Traveling Wave, and Kv. and Kw. of Arrester Plus Ground Resistance, as Functions of the Arrester Discharge Current. Case of a 3-kv. pellet-type arrester with 15-ohm ground resistance, located at end of line

While it is desirable to have low ground resistances with arresters of all ratings to gain maximum protection, it is obvious that a high ground resistance will more seriously penalize protection on the lower-voltage circuits, because on the lower-voltage circuits the surge voltage must be reduced to a very small percentage of the possible lightning voltage on these circuits. Fig. 9 shows the volt-time protective characteristic of a small compression-chamber arrester for the protection of 440 and 550-volt secondary circuits. This arrester without series ground resistance holds the voltage to a value well below the 60-cycle one-minute test of secondary apparatus. If this arrester has a 15-ohm ground resistance in series with it, and the same 800-amp. discharge passed through the combination, the *IR* drop across the ground resistance is 12 kv. which is over 700 per cent greater than the drop across the arrester. The same ground resistance with a 3000-volt arrester increases the stress on adjacent insulation by only about 200 per cent of the arrester voltage. For the 15-kv. arrester with a 15-ohm ground resistance, the *IR* drop across the ground resistance adds only about 50 per cent to that across the arrester. In practice, two or three phases are connected to the same ground and the current through the ground resistance may be large.

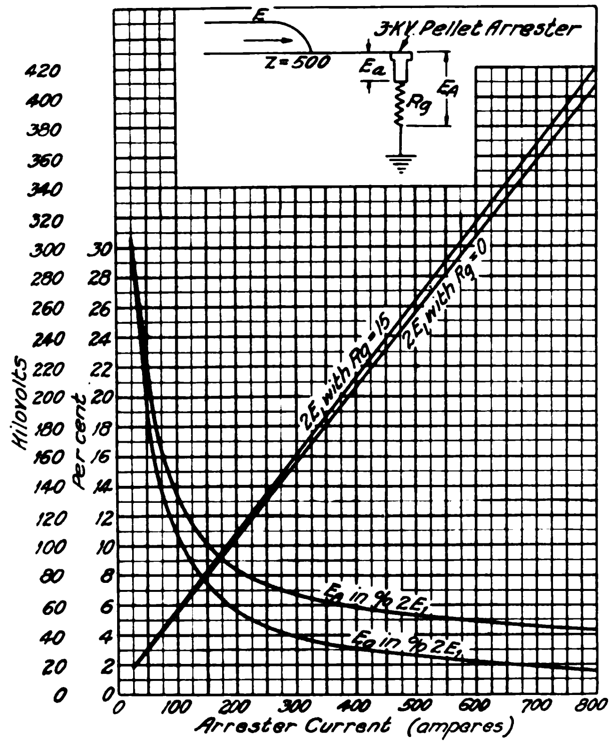

Fig. 8. Voltage with Arrester and with Arrester Plus 15-ohm Ground Resistance in Percent of $2E$ for Various Values of Arrester Discharge Current. Here E is wave voltage which with no arrester would reflect to $2E$; and $2E$ is plotted as a function of arrester discharge current

For a discharge current of the order of 800 amp. the volt-ampere characteristics for the pellet arresters are from two to two and a half times the effective 60-cycle rating of the arrester. With the higher-voltage station-type oxide-film arresters, in which a greater factor of safety in valve rating must be introduced for excessive system voltage, the crest volt-ampere characteristic is about 3.5 times the effective 60-cycle arrester rating.

Location of Arresters

The scientific application of lightning arresters demands, first, the recognition of the extremely transient or steep-wave-front nature of the dangerous potentials involved with the direct or indirect effects of lightning; and second, the acknowledgment of the hyperbolic volt-time breakdown characteristic of apparatus insulations in which the voltage to cause failure becomes lower with increased time of voltage application. These fundamentals, together with the fact that the effects of repeated applications of excess voltage on apparatus insulations may be more or less cumulative, make the relative location of the arrester a pertinent factor in the problem of protection.

Extensive service experience, laboratory tests, and theoretical considerations point to the greater security of a distribution transformer against lightning damage when the arresters are on the same pole, which of necessity means that the arresters are close to the transformer. In transmission practice involving the larger station-type arresters, particularly at the higher-voltage generating and substations, the physical arrangement and extent of apparatus makes it rarely possible to place the arrester directly adjacent to the transformer or other apparatus to be protected. However, the handicap of arrester separation in the larger stations may often be more or less counterbalanced by the favorable action of the electrostatic capacitance of the terminal apparatus or station structure and the decreased surge impedance brought about by the termination of the line into multiple circuits and buses in the station. When a traveling wave reaches such an installation involving a comparatively low surge impedance in buses and connections, and a relatively concentrated capacitance in the apparatus, the wave front is sloped off so that the voltage gradient on the circuit between the arrester and the other apparatus will be very much less than the gradient over a similar length of circuit on the open line. The equivalent surge impedance of the complex circuit is equal to the reciprocal of the sum of the reciprocals of the impedance of individual circuits. If the surge impedance is reduced to the fraction $\frac{1}{n}$, the voltage is reduced to the fraction $\frac{2}{n+1}$. For example, if the surge impedance is reduced to 1/10, the wave voltage is reduced to 2/11, the formula being $E_2 = E_1 \frac{2}{1+\frac{Z_1}{Z_2}}$. This, however, does not include the increase in voltage due to reflections at the far end

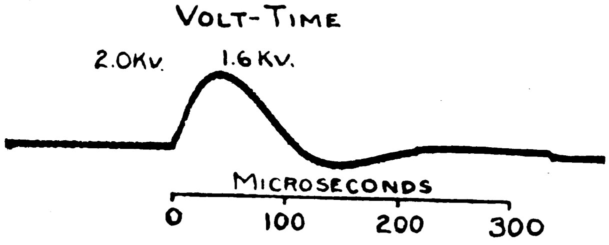

Fig. 9. Cathode-ray Oscillogram, Volt-time Characteristic of 0—750-volt Compression-chamber Arrester

of the Z_2 circuits. Since the steepness and length of the incoming wave are unknown, it is impossible to definitely evaluate the benefits of the aggregate surge impedance; and the action depends upon the electrical and physical set-up of each individual case. The best engineering practice, therefore, is to place no particular dependence on this action but rather to locate the arrester as close as practicable to the transformers or other apparatus to be protected. Where the separation between arrester and transformer is of necessity several hundred feet it may in some cases be desirable to shield the intervening circuit and buses with several overhead grounded conductors which serve to decrease the potentials induced on the station side of the arrester and also to minimize the reflections of the arrester voltage at the terminals of inductive equipment.

Where lines enter a station through cables, the latter should be protected at the junction of the line and cable. While Fig. 3 indicates that the low surge impedance of the cable will greatly reduce the value of incoming voltages, reflections within the cable progressively increase the stress on the cable insulation; and if the length of the incoming wave is great compared to the length of the cable, thus permitting several reflections each with its increased voltage in the cable, the stress on the cable insulation may ultimately approach the voltage of the incoming wave. From a case calculated, if the original incoming wave were 20 times the length of the cable, the voltage of the latter could be built up by the successive reflections to nearly 90 per cent of the wave voltage on the line. Dielectric losses in the cable account for very negligible absorption of energy. It must be remembered that when a wave leaves the cable in the station, the voltage approaches double value at the junction of the cable and open station wiring, and that this voltage again approaches double where the station wiring terminates at a transformer or other inductive equipment. It is therefore desirable to have an arrester on the station bus in addition to the arresters out at the junction of the overhead lines and cables.

A scheme which apparently has some merit, but which has probably not been tried, is to extend a cable three or four spans along the poles with the sheath insulated from ground, so that a portion of the wave is transferred from the exposed line to the sheath. The sheath can then be grounded through a resistance to absorb this wave energy.

Probably one of the most difficult protective problems is that involved with rotary apparatus directly connected to exposed overhead lines. The space-factor in rotary equipment, together with the fact that insulation must operate dry and without reinforced end-turn insulation, generally results in a smaller factor of safety in insulation than is obtained with transformers. There are many cases in practice where generators or motors are directly connected to exposed feeders and satisfactory protection of this equipment requires reducing the line surges to the very minimum at the terminals of the apparatus. Extremely low ground resistance is imperative and the arrester should be close to the apparatus terminals to avoid the increased insulation stress due to reflection. Where the insulation strength is below normal and the voltage reduction by arresters does not prove sufficient for protection, it may be desirable to introduce a one-to-one insulating transformer between the rotary machine and the exposed line.

Line Protection

While the greatest economy in lightning protection unquestionably lies in the application of arresters at the stations and apparatus terminals, the increasingly critical attitude towards line flashovers and service interruptions is directing a great deal of thought to the problem of protecting the line insulation against flashover. With the grounded-neutral circuits the flashover of line insulation by lightning will usually result in a service interruption; but this actually depends upon the point of the 60-cycle wave at which the lightning impulse occurs. If the impulse happened to occur while the 60-cycle voltage was passing through zero, a follow-current arc would be unlikely and no interruption would ensue.

There seem to be four measures which might be looked to either individually or in combination to reduce the service interruptions from line flashovers. These are: first, the overhead ground wire; second, lightning arresters liberally applied along the line; third, the use of fused arcing horns or rings on insulator strings; and fourth, the employment of the Petersen grounding coil or reactor. The first two measures are by the way of eliminating or reducing the lightning voltages on the line to a value below line insulation flashover. The second two measures do not alter the magnitude of the lightning potentials on the line, but prevent the operation of breakers and service interruption following a lightning flashover.

It is of course entirely feasible, though not generally economical, to design transmission lines for immunity from lightning flashover. A 220-kv. line has recently been considered with this result in mind. The average height of the line conductors is kept down to about 36 ft. and, assuming the maximum possible cloud-to-earth gradient to be 100 kv. per foot, the possible induced voltage on the line conductors would be 3600 kv. Two overhead ground wires are assumed to reduce this voltage by 60 per cent or to about 1450 kv. The line insulation, together with the grading shields, has a flashover of 2300 kv. Theoretically, there should be few if any induced lightning flashovers on such a line; but experience is still necessary to confirm this anticipation. It would seem that the cost of lightning interruptions to service after a line is in operation might justly be applied toward adjusting the line for greater immunity from lightning flashovers. The greatest single factor lies unquestionably in minimizing the height of the line above earth. The lower the line, however, the less is the effect of overhead ground wires.

Overhead ground wires have come into almost universal favor; and service records and line interruptions, together with surge-recorder data, evidence a very marked reduction in line troubles by their use. A 50 per cent reduction in induced voltage by a ground wire may mean an 80 or 90 per cent reduction in the number of flashovers. In addition to reducing the induced voltage, the ground wire increases the attenuation in wave travel along the line. The actual protective benefits of the ground wire in per cent reduction of induced voltage depends upon the height, physical configuration, and the frequency and effectiveness of the points at which the ground wire is earthed. The cost of the overhead ground wire varies through a fairly wide range, depending on the construction; but for the higher-voltage lines the cost will probably run from $500 to $1000 per mile.

The application of arresters along the line to prevent insulation flashovers has often been proposed, but the cost of arresters has been a prohibitive factor except in a few instances. Such instances are where repeated line flashovers occurred at badly exposed points, such as where a line crossed over high, rocky, topography; arresters at such points have greatly improved service reliability. The fact that lines are being constructed with two and occasionally three overhead ground wires involving an expenditure of $1500 to $3000 per mile mainly to reduce line flashovers is evidence that arresters of the proper physical proportions for line application is a worthy consideration. The arrester for line protection would not have to present as good a protective characteristic as is considered desirable for station protection; and thus the line arrester could have higher internal resistance which would permit more energy to be absorbed. A poorer protective characteristic is justifiable because, first, repeated applications of voltage just below the insulator flashover would not be cumulative and therefore if the arrester held the voltage to 15 or 20 per cent below the insulator flashover the result would seemingly be satisfactory; second, that reflections of the arrester voltage to double value which can occur at the terminals of inductive apparatus in the station would not be possible with the line arrester application. On the other hand, the line protection problem is dealing with air dielectric wherein the impulse ratio is generally less than that in the apparatus involving composite, solid, and liquid insulations. The natural question is how frequently line arresters would have to be applied to entirely prevent insulation flashovers. This would seemingly depend entirely upon the steepness of the lightning waves on lines, and the resulting potential gradient along the conductor, as well as the attenuation factor. The question can probably not be answered until more data are available on the actual wave fronts from lightning. These data should be forthcoming this season. An idea of the wave fronts will permit a good ground for speculation as to the permissible separation of the arresters along the line; but any theoretical conclusion would have to be confirmed by practical experience.

In considering line arrester application, it is noteworthy that benefits may be expected from applying the arresters on only one phase or conductor of the line. If the discharge of the arresters on the one phase appreciably reduces the voltage on that phase, the latter will cause a lesser reduction of the voltage on the other two phases by capacitance effect. The reduction of voltage on one phase by the arresters enables that phase to partially simulate an overhead ground wire in affecting some voltage reduction on the other two phases. In such an application to lines having other than horizontal arrangement of conductors, the arresters might be put on the highest conductor or phase wire, which would be subject to the highest induced lightning voltage.

While the fused arcing ring or horns seem to have some merit in preventing line interruptions following lightning flashovers, the scheme has the objection of requiring frequent patrol of the line and fuse replacements. Service data on this scheme merit careful observation.

A Petersen grounding coil or reactor inserted between the neutral and earth seems to be entitled to consideration. The Petersen coil is enjoying considerable favor among European engineers but only one or two test installations have been made in this country. With such transmission problems as instability and the extremely heavy short-circuit currents imposing extreme duty on circuit breakers on transmission systems, there is some tendency to favor grounding the neutrals through either resistance or reactance. In general, the reactance is said to be cheaper. While the ohmic value of neutral grounding resistances and reactances in use is below that of the Petersen coil, there seems to be increasing discussion and some favor toward going all of the way to the Petersen coil in the neutral.

The Petersen coil supplies the charging current to ground of the two non-grounded lines when one becomes grounded. The reactance is so proportioned that this charging current will provide full leg voltage across the reactor. This accomplishes two things: first, it provides a path of low impedance for the charging current, thus shunting it away from the flashover ground fault; second, it provides a path of high impedance to the short-circuit current through the fault. The combined effect is to enable the fault to clear without switch operations.

The Internal-combustion Engine in Railroad Service

Advantages of Electrically Transmitting the Engine's Power to Wheels—Factors Determining Choice of Gas-electric Drive for Rail Cars and Oil-electric Drive for Locomotives—Tabulated Data of Increase in Number of Units in Service, Performance, and Operating Costs

By S. T. DODD
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THE success of the internal-combustion engine in automobiles, airplanes, and marine service makes the application of the same type of engine to transportation on railroads both logical and necessary. Two lines of development have been followed, and these may be kept distinct and considered independently of each other.

The first line of development has utilized the light high-speed gasoline engine. The advantage of this type of engine is particularly evident where reduction of weight is an essential feature. The objections to the engine are the cost of gasoline as a fuel and the increased maintenance due to carburetors and ignition systems. These disadvantages, however, are offset by the lighter weight of the engine; and, for high-speed car service, the decreased weight of the engine and equipment has made this the type of motive power which has received the most favor.

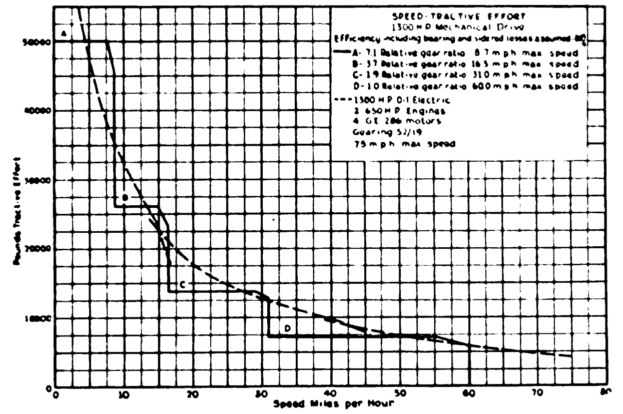


Fig. 1. Comparison of the Speed-tractive Effort Curves of Two 1300-hp. Internal-combustion-engine Locomotives, One with Mechanical Drive and the Other with Electric Drive

The other line of development has employed engines of the Diesel type. The speed limitation of this type of engine requires greater weight of engine and transmission system; but for certain types of service this increased weight is not of much consequence compared to the lower cost of fuel and the reduced locomotive maintenance resulting from the elimination of carburetors and ignition systems. This type of engine has therefore been principally employed in locomotive service.

Along these two lines have been developed the gas-electric car and the oil-electric locomotive. The fundamental theory of using an internal-combustion-engine with electric transmission is the same in both cases; but the internal-combustion-engine car with electric transmission has been developed as a gas-electric car on account of the importance of reduced weight of power plant, while the internal-combustion-engine locomotive with electric drive has been developed along the line of the oil engine or Diesel engine on account of the importance of reducing operating expense and in spite of the increased weight of power plant.

TRANSMISSION SYSTEMS

Of the various systems of power transmission between engine and driving wheels, the only type which has a wide application in practice is electric transmission. A number of different types of transmission have been developed experimentally, but for any considerable weight of train none of these has been found so successful as electric transmission; some of them, however, might be briefly reviewed.

Mechanical Gearing System

The simplicity of a mechanical connection between engine and driving wheels is obvious; but, when large powers are to be transmitted, the complication of the gearing, with its various combinations for forward and reverse and for different speeds and gear shifts, makes the weight and cost of the equipment comparable to that for electric transmission.

In addition to this, there is the objection of rigidity. The variations of track and torque are transmitted directly through the gearing to the engine and increase the maintenance of the engine. All engine builders agree that for reasonable maintenance there must be a cushioning effect of some sort in the drive between the engine and the track. Such an effect is supplied by electric transmission but is entirely absent with mechanical gearing.

Another objection is that any mechanical gearing involves a step-by-step variation of the torque and speed. Fig. 1 shows the variations in torque and speed of a 1300-hp. locomotive having mechanical transmission, as compared with a locomotive of the same capacity having electrical transmission. It will be noted that with mechanical transmission there are only a few points where the engine is running at its normal speed. It is either throttled down to less than normal speed and normal horsepower or it is running at over speed.

Still another objection is that the shift from one gear combination to the next cannot be accomplished without interrupting the application of power, and this results in a definite break of torque and a definite loss of speed at the moment of transfer.

All such objections are eliminated by the use of electric transmission.

Hydraulic System

There have been a number of attempts made to design a hydraulic transmission using oil as the medium of power transmission from the engine to the driving wheels. One of the chief objections to this type of transmission is the rigidity between the drivers and the oil engine. In addition, there are the variations in the characteristics of the oil under heat and pressure, and the difficulty due to leakages in piping, carrying oil under high pressure between the engine and the motors on the driving wheels.

Pneumatic System

Much study has been directed toward the development of air transmission. This system would have the advantage of interposing a resilient medium between the engine and driving wheels, but it has a rather low efficiency. It has been calculated that the overall efficiency of a locomotive with air transmission would be between 13.4 and 15.3 per cent. This is about one-half the efficiency which can be obtained with electric drive.

Electric System

The eventual fact is that, in spite of the objections which have been made to electric transmission on the ground of cost and weight and the advantages which have been claimed for some other type of transmission, there is no development of motor cars and oil-engined locomotives anywhere in the world comparable to that being carried on in the United States with engines equipped with electric transmission.

Some of the principal advantages of electric transmission which have caused it to be so generally adopted may be briefly enumerated.

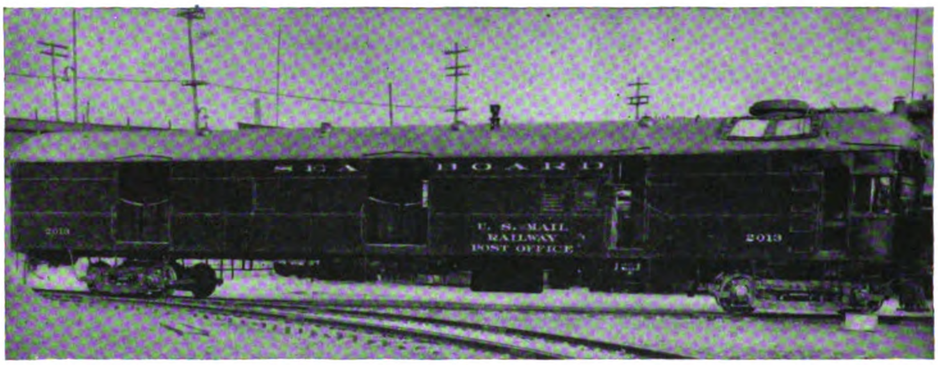


Fig. 2. Gas-electric Rail Car (290 hp.) on the Seaboard Air Line

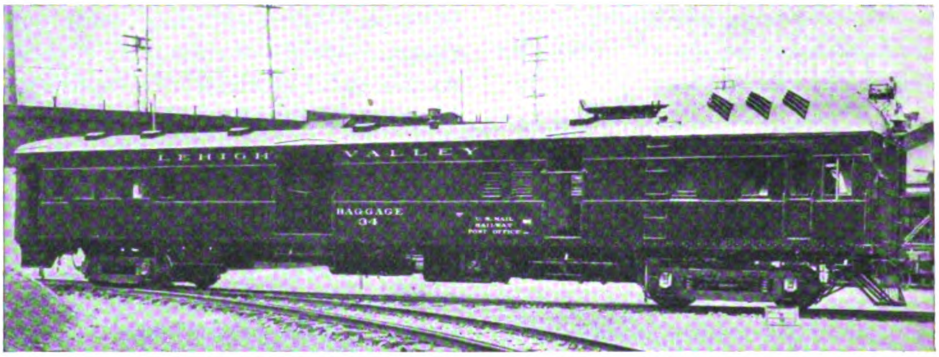


Fig. 3. Gas-electric Rail Car (with Two 290-hp. Units) on the Lehigh Valley R.R.

Simplicity of Control

In electric transmission an engine-driven electric generator furnishes electric power for motors on the driving wheels. Variations in the speed of the train and reversal of movement are accomplished by varying the field of the generator or reversing the electric connections to the motors. The convenience and simplicity of this method of control are obvious when compared with the gear shifts or similar movements required to accomplish the same results with any form of mechanical transmission.

Cost of Maintenance

The cost of maintenance of the electric equipment on electric motor cars and locomotives is a point on which there is widespread and very well established information. The cost of maintenance, however, of the nest of gears required for controlling a heavy car or locomotive with mechanical transmission apparently runs into excessive amounts.

Table I is copied from the Report of the Committee on Automotive Rolling Stock of the American Railway Association, Mechanical Division, April 26, 1927. It shows that, considering the average operating cost of rail cars reported by a number of Class I railroads, the cost of repairs on the mechanically driven car is approximately double that of the cost of repairs on the electrically driven car. This holds in spite of the greater weight and greater capacity of the electrically equipped cars which data appeared in another part of the same report.

TABLE I

GENERAL AVERAGE OF RAIL-CAR OPERATING COSTS

(As reported by several Class I railroads)

CENTS PER MILE

Type of Equipment	MECHANICAL		ELECTRIC	
	Single	Trailer	Single	Trailer
Crew	18.69	22.93	18.85	20.79
Fuel	4.59	6.05	10.45	12.10
Lubricating oil	0.86	.90	.88	1.00
Supplies Cleaning Enginehouse	2.83	3.12	1.66	2.10
Repairs	11.40	10.85	6.31	5.45
Total	38.37	43.85	38.15	41.44
Average daily mileage	101	122	165	203

Multiple Power Plant

With increased weight of trains and increased power of equipment, it is frequently more economical to employ two or more engines than one large engine of the same aggregate capacity. Such an installation would be practically impossible with mechanical gearing but is easily accomplished with electric transmission.

Double-end Control

Where it is necessary or desirable to control a train or locomotive from two or more operating positions, mechanical transmission would involve running levers, gear-shift rods, etc. to each of the operating positions. With electric transmission, however, the same results can be obtained very simply by the use of a set of control wires.

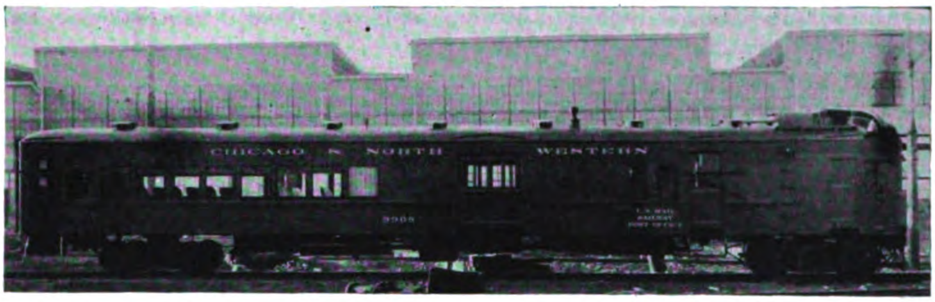


Fig. 4. Gas-electric Rail Car (225 hp.) on the Chicago and North Western R.R.

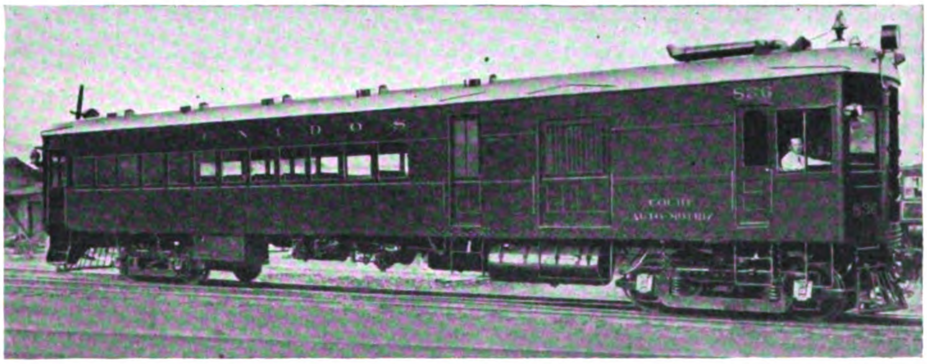


Fig. 5. Gas-electric Rail Car (290 hp.) on the United Railways of Cuba

RAIL MOTOR CARS

Preliminary attempts to apply the internal-combustion engine to railroad service were made in the years 1900-1910. Many of the early attempts, however, were with small engines and light cars of the bus type, being essentially gasoline buses equipped with flanged wheels and not conforming to A.R.A. standards. What may be considered the first earnest attempts to develop rail motor cars conforming to A.R.A. standards date from about 1910.

In 1907, W. R. McKeen, Supt. of Motive Power of the Union Pacific Railroad, designed a motor car with mechanical drive, and the McKeen Motor Car Company built a number of this type of car. The weight of these cars was approximately 50 tons. They were equipped with engines ranging from 150 to 200 hp., mounted on the front truck of the car and driving a single axle of the truck through a sprocket wheel and chain. In the period from 1907 to 1916 approximately

200 of these cars were built and put in service, largely on the Harriman Lines, allied with the Union Pacific Railroad.

About 1909 the General Electric Company designed and built a motor car using electric transmission. From that date to 1916, approximately 90 of these cars were built and put in service. The standard power plant in this type of car consisted of an engine rated at 175 hp. driving a generator having characteristics suitable to absorb the power of the engine and furnish electric power to motors geared to the driving wheels. At last accounts, approximately one-half of these cars are still in service.

However, the real development of the rail motor car did not begin until about 1920. At that time the increasing cost of railroad operation, the competition of automobiles and trucks, and the demonstrated results of gas-electric car service awakened the interest of a number of different railroads, car builders, and engine manufacturers.

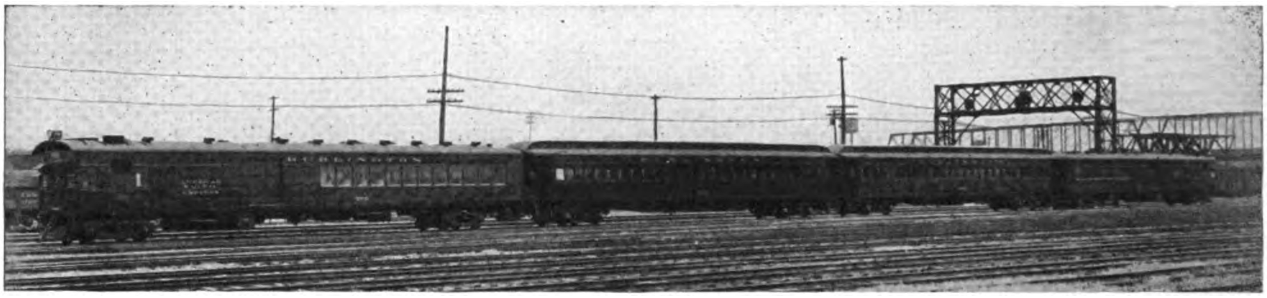


Fig. 6. Two Gas-electric Rail Cars, with Two Coaches Between, Coupled up for Demonstration of Dual-control Operation

The steady growth of the application of this type of car can best be illustrated by the figures in Table II.

TABLE II

ORDERS FOR RAIL MOTOR CARS AND TRAILERS

	1922	1923	1924	1925	1926	1927	1928
For service in the U.S. . .	51	77	120	149	142	180	175
For service in Canada. . .	7	3	12	7	4	9	10
For export.	1	22	. .	34	32	12	9
Total	59	102	132	190	178	201	194
Motor cars.	50	93	112	171	161	176	172
Trailers	9	9	20	19	17	25	22

This table is quoted from the *Railway Age* of January 5, 1929, and shows that the railroads are increasing their use of this type of equipment at the rate of about 200 cars each year.

Since 1922 approximately 800 cars of this type have been built for railroad service. The demand for gradually increased weights of cars and horsepower of equipment is illustrated by Tables III and IV, which are also copied from the *Railway Age* of January 5, 1929.

These tables illustrate very strikingly the present tendency of the demand for motor cars. While in 1925 the average car had a weight of 50,000 to 75,000 lb. and was equipped with a power plant of 150 to 250 hp., in 1928 the demand is evidently for a car having a weight of 100,000 to 150,000 lb. and equipped with a power plant of 250 to 400 hp.

TABLE III

COMPARISON OF RAIL MOTOR CAR WEIGHTS (U. S. AND CANADA)

Weights	1926	1926	1927	1928
25,000 lb. and under.	6	7	. .	. .
Over 25,000 lb. to and incldg. 50,000 lb.	19	7	. .	. .
Over 50,000 lb. to and incldg. 75,000 lb.	74	2	4	. .
Over 75,000 lb. to and incldg. 100,000 lb.	27	79	29	5
Over 100,000 lb. to and incldg. 125,000 lb.	7	32	88	69
Over 125,000 lb. to and incldg. 150,000 lb.	. .	5	21	53
Over 150,000 lb	. .	1	. .	9
Unclassified.	. .	. .	26	22

TABLE IV

POWER PLANT CAPACITY OF RAIL MOTOR CARS (U. S. AND CANADA)

Horsepower	1925	1926	1927	1928
100 or less.	13	14	2	5
Over 100 to and including 125.	5	7	. .	1
Over 125 to and including 150.	9	. .	. .	3
Over 150 to and including 175.	20	1	. .	1
Over 175 to and including 200.	49	3	3	1
Over 200 to and including 250.	36	65	43	13
Over 250 to and including 300.	2	26	76	64
Over 300 to and including 350.	. .	. .	. .	24
Over 350 to and including 400.	2	. .	. .	17
Over 400.	. .	19	16	25
Unclassified	. .	. .	24	7

TABLE V

COST PER TRAIN-MILE (CENTS)

	Steam Train	Gas-Electric
Wages: Engine and train crews.	28.5	17.9
Fuel: Coal or gasoline.	28.0	8.01
Lubricant	1.01	1.01
Terminal inspection and engine-house expense	2.0	1.25
Labor: Cleaning, icing, and watering. . . .	1.18	0.92
Miscellaneous supplies	0.75	0.52
Repairs: Labor and material, total train.	21.0	5.0
Sub-total.	82.5	34.61
Depreciation at 10 per cent.	. . . .	7.15
Interest at 6 per cent.	. . . .	4.3
Grand total.	82.5	46.06

Operating Costs and Results

The operating costs of this type of car will depend very largely upon the operating and service conditions. Such cars are running in regular service from 200 to 400 miles per day, and in general the cost of operation runs from 35 to 50 cents per train-mile. As an example, Table V is presented which shows the cost of operating an 85-ton 2-car 275-hp. gas-electric train as compared with the steam train which it replaced.

A still more detailed statement in Table VI shows the cost of operating two gas-electric motor cars each hauling a 35-ton trailer and operating an average of 251 miles per day. The figures given are the result of 10 months' operation.

TABLE VI

COST OF TEN MONTHS' OPERATION OF TWO GAS-ELECTRIC MOTOR CARS

Average Trip 251 Miles Daily with 35-ton Trailer—Train Weight 83 Tons—Power Plant 225-hp. Engine

Total motor car-miles	141,062
Total steam train-miles	8,032
Total train-miles	149,094
Gasoline: Gallons	73,461
Cost: Gasoline per gallon (cents)	13.18
Train-miles per gallon	1.92
Car-miles per gallon	3.76
Lubricating oil: Gallons	2,017
Cost of oil per gallon (cents)	50.28
Train-miles per gallon	71.16
All expense per train-mile, including interest, depreciation and steam service	35.23
COST PER TRAIN-MILE (CENTS)	
Repairs: Labor	1.30
Repairs: Material	0.83
Fuel: Gasoline	6.84
Lubricants	0.74
Enginehouse expense, inspection	1.26
Other supplies and expense	1.28
Wages: Train and engine crew	15.15
Sub-total	27.41
Substitute steam service	2.43
Total	29.84
Interest on investment	2.90
Depreciation	2.49
Grand total (cents per train-mile)	35.23
SUMMARY	
Total scheduled mileage, 10 months' operation	149,094 miles
" motor car mileage	141,062 "
" steam-train mileage	8,032 "
" steam-train mileage due to heavy traffic	6,024 "
" steam-train mileage due to motor cars out for repairs (equivalent to four round trips)	2,008 "
Percentage of scheduled mileage covered by motor cars	98.7 per cent

OIL-ENGINE LOCOMOTIVE

The application of the internal-combustion engine to locomotive service follows as a direct consequence of the development of the rail motor car. As a matter of fact it is rather difficult to draw the line between motor cars and locomotives. Whether a particular equipment is to be regarded as a motor car or as a locomotive depends largely on the service in which the user chooses to put it.

Of the gas-electric cars built by the General Electric Company between 1909 and 1916, as mentioned in one of the previous paragraphs, four units were built specifically as locomotives. These units were each equipped with two 175-hp. engines and four motors, making a locomotive approximately 60 tons in weight, and were used for freight service on the Minneapolis, St. Paul, Rochester, and Dubuque Railway, commonly known as the Dan Patch Line. In addition to these, a number of the modern high-powered motor cars, particularly with double-engine equipment, are being used in locomotive rather than in motor-car service.

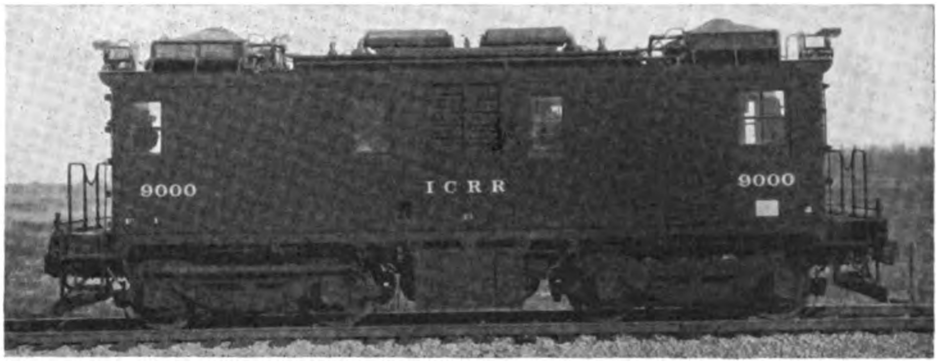


Fig. 7. Oil-electric Freight Locomotive (100 Tons, 600 hp.) for the Illinois Central R.R.

Units built strictly for locomotive service have two or three outstanding features that distinguish them from motor cars. It is evident that weight efficiency is not so important in a locomotive as in a motor car where light weight in the power plant is a prime requisite. Railroads dislike to use gasoline in large quantities around freight and switching yards; and the Diesel type of engine has a fuel efficiency that is approximately double that of the carburetor type of gasoline engine. On account of some or all of these features, the internal-combustion locomotive has been developed as an oil-electric locomotive rather than as a gas-electric locomotive.

The most extensive practical development of the oil-electric locomotive has been the contribution of American engineers and manufacturers. To this development the Ingersoll-Rand Co. and the McIntosh and Seymour Co. have contributed engines especially designed for locomotive service. The American Locomotive Co. has designed and built the majority of the mechanical equipment; and the General Electric Company has furnished the electrical equipment.

Since the fall of 1925 the locomotives listed in Table VII have been built and placed in freight, passenger, and switching service. In addition to these the following locomotives have been built with Westinghouse equipments: An 87-ton locomotive with Westinghouse-Beardmore engines, in service on the Long Island Railroad; a 136-ton locomotive with Knudsen engine, built by the Baldwin Locomotive Works; a

TABLE VII

OIL-ELECTRIC LOCOMOTIVES IN SERVICE IN UNITED STATES AND CANADA

No.	Approximate Weight Each	Engine Builder	Engine Rating	Electrical Equipment
24	60 tons	Ingersoll-Rand	300 hp.	General Electric
9	100 tons	Ingersoll-Rand	600 hp.	General Electric
1	73 tons	McIntosh & Seymour	300 hp.	General Electric
1	128 tons	Ingersoll-Rand	300 hp.	General Electric
1	145 tons	Ingersoll-Rand	750 hp.	General Electric
1	165 tons	McIntosh & Seymour	900 hp.	General Electric

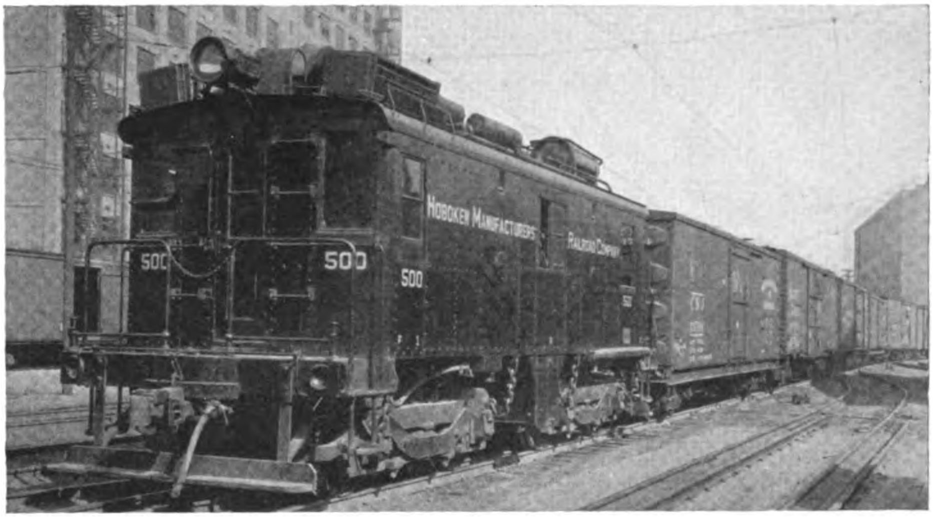


Fig. 8. Oil-electric Switching Locomotive (60 Tons, 300 hp.) for the Hoboken Manufacturers' Railroad Company

TABLE VIII

OPERATING RATIOS OF OIL-ELECTRIC LOCOMOTIVES

	Service Hours	Load Factor Per Cent	Kw-hr. Per Gal.	Ratio Lub. Fuel Per Cent
60 ton, Railroad "A" *(Sept. 1 and 2, 1925)*	16	28	8	2.7
60 ton, Railroad "A" *(Nov., Dec., Jan., 1925 and 1926)*	1052	10.5	6.02	2.1
60 ton, Railroad "A" *(Feb., 1926)*	293	8.4	6.06	2.95
60 ton, Railroad, "B" *(Jan., 1926)*	162	8.6	5.5	3.6
60 ton, Railroad "B" *(Feb., 1926)*	214	8.2	5.8	3.3
60 ton, Railroad "C" *(Jan., 1926)*	394	8.2	6.15	2.6
60 ton, Railroad "C" *(Feb., 1926)*	365	7	5.6	2.75
100 ton, Railroad "D" *(Dec., 15, 1925)*	40	33	8.05	1.0
100 ton, Railroad "D" *(Feb. 15-27, 1927)*	220	15.1	7.5	1.2
100 ton, Railroad "E" *(Dec. 15, 1925)*	40	23.6	8.05	0.95
100 ton, Railroad "F" *(Oct. 1, 1927)*	5.5	49.9	8.18	1.5

2660-hp. locomotive with Beardmore engines, in course of construction by the Canadian National Railway.

Operating Results and Cost

The majority of the locomotives in service up to the present time have been built and used for low-speed switching service. This can readily be inferred from the fact that Table VII shows about two-thirds of the locomotives are of approximately 60 tons with engine horsepowers of about 300.

Any electric-drive locomotive in switching service can handle trains up to approximately 20 times the weight of the locomotive itself, but the maximum speed at which it can handle such a train is determined by the engine horsepower. A locomotive of 60 tons weight can handle a train of 1200 tons; but with an engine equipment of only 300 hp. it can readily be calculated that the maximum speed on level track will be something in the neighborhood of 5 mi. per hr.

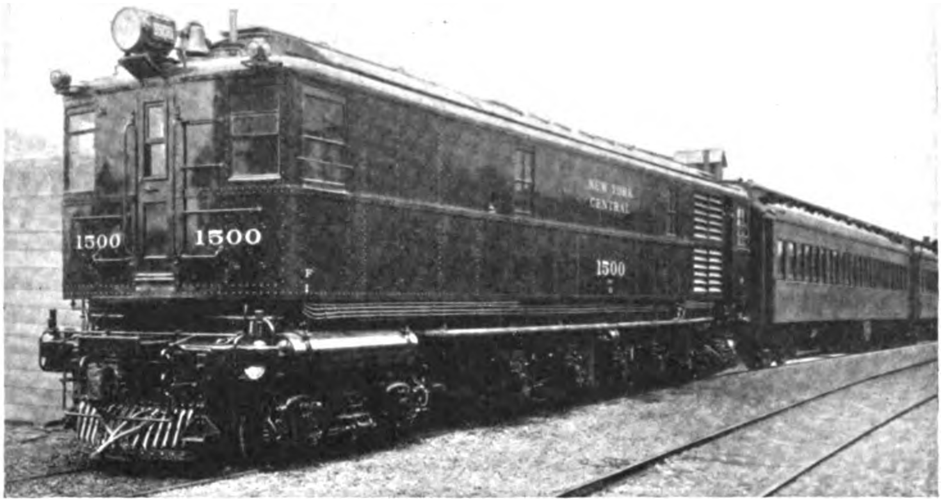


Fig. 9. Oil-electric Passenger Locomotive (165 Tons, 900 hp.) for the Putnam Division of the New York Central R.R.

This question of horsepower per ton of locomotive or per ton of train is one of the determining features in the application of the oil-electric locomotive or of any locomotive.

In motor-car service, where the gasoline engine is the standard prime mover, practice has demonstrated that 3 to 4 hp. per ton of train is necessary to develop the schedules required in branch-line service. Very few gasoline-electric cars are operating in service where there is an equipment of less than 3 hp. per ton of train.

In local freight service, a power equipment of about 1 hp. per ton of train is approximately what is demanded by ordinary operating conditions.

For switching service, the power equipment may be as low as ¼ hp. per ton of train. This equipment is ordinarily acceptable, but as has been mentioned, a maximum speed of not more than 5 mi. per hr. on level track will be obtained; and such limited power is not acceptable where grades of any amount are encountered.

In switching service, the loads are intermittent and the average load factor is low. As a consequence, records of switching locomotives do not show the economy in fuel consumption that could be expected from the same type of engine if it were operated at about full load. Table VIII is quoted from the report

TABLE IX

MAIN-LINE TEST OF 100-TON OIL-ELECTRIC LOCOMOTIVE IN FREIGHT SERVICE

Dec. 15th to 16th, 1925

Trailing load: 5 box cars, 1 passenger coach, and 1 cabin car.	
Total train weight including locomotive	337 tons
Miles traveled	537
Total time elapsed	40 hr. 23 min. 45 sec.
Actual running time	28 hr. 44 min. 45 sec.
Detention due to railroad	9 hr. 26 min. 45 sec.
Detention due to locomotive	2 hr. 12 min. 15 sec.
Total detention	11 hr. 30 min. 00 sec.
Average speed	18.7 mi. per hr.
Maximum speed	30 mi. per hr.
Total kw-hr. generated	3,810
Average oil-engine load factor	23.6 per cent
Maximum oil-engine load factor	74.1 per cent
Total gallons fuel oil consumed	473

Total gallons lubricating oil consumed	5
Total gallons water consumed	Negligible
Total ton-miles	202,449
Total fuel cost: Fuel oil at $0.05 per gal. Lub. oil at $0.50 per gal.	$26.15
Fuel cost per 1000 ton-miles	$12.90
Fuel cost per locomotive-mile	$4.86
Fuel cost per kw-hr. generated	0.685 cents
Lb. fuel oil per kw-hr. generated	0.895
Lb. fuel oil per locomotive-mile	6.350
Lb. fuel oil per 1000 ton-miles	16.85

NOTE.—The oil engines were operated continuously for test purposes. An additional fuel saving could have been obtained by shutting down the engines for detentions of over five minutes' duration.

of the Committee on Locomotive Design and Construction, American Railway Association, May 7, 1927, and gives the load factor, the kilowatt-hour output per gallon of fuel and the ratio of lubricating oil to fuel oil for a number of records taken on oil-electric locomotives during the years 1925 to 1927.

The first record and the last four are of special test runs, which accounts for the high load-factors. The other records are of regular commercial service runs and it will be noted from the table that the load factor under such conditions averages something less than 10 per cent. In other words, a 300-hp. locomotive would be developing only about 30 hp. in this average switching service and at this load would develop, at the generator, approximately 6.5 kw-hr. per gallon of fuel oil. This in turn is equivalent to about 7.5 hp-hr. at the driving wheels per gallon of fuel. With fuel at five cents per gallon, this is equivalent to a fuel cost of 0.66 cents per horsepower-hour.

TABLE X

MAIN-LINE TEST OF 100-TON OIL-ELECTRIC LOCOMOTIVE IN PASSENGER SERVICE, OCT. 13, 1927

Start of test	7:00 a.m. Oct. 13, 1927
Conclusion of test	12:30 p.m. Oct. 13, 1927
Trailing load:	
Four passenger coaches	165.5 tons
Total train weight including locomotives	280.5 tons
Miles traveled	183.7
Total time elapsed	5 hr. 30 min.
Actual running time	4 hr. 51.5 min.
Detention due to railroad (inc. station stops)	34.5 min.
Detention due to locomotive	4.0 min.
Total detention	38.5 min.
Schedule speed	33.4 mi. per hr.
Maximum speed	56 mi. per hr.
Total kw-hr. generated	1098
Average oil-engine load factor	49.9 per cent
Maximum oil-engine load factor	78.8 per cent
Total gallons fuel oil consumed	134
Total gallons lub. oil consumed (estimated)	2
Total gallons water consumed	Negligible
Total ton-miles	51,528
Total fuel cost: Fuel oil at $0.05 per gal. Lub. oil at $0.50 per gal.	$7.70
Fuel cost per 1000 ton-miles	14.95 cents
Fuel cost per train-mile	4.19 cents
Fuel cost per kw-hr. generated	0.701 cents
Lb. fuel oil per kw-hr. generated	0.891
Lb. fuel oil per train-mile	5.32
Lb. fuel oil per 1000 ton-miles	18.99
Train-miles per gal. fuel	1.37
Kw-hr. generated per gal. fuel oil	8.18
Kw-hr. generated per 1000 ton-miles	21.3

NOTE.—The train made six station stops.

It will also be noted from the table that the lubricating oil consumption of these engines runs from 2 to 3 per cent of the fuel oil consumption. This ratio also depends largely on the load factor, the lubricating oil consumption depending on the time the engine is in service while the fuel oil consumption is determined by the load on the engine.

Freight Service

One of the locomotives listed in Table VII, *viz.*, the 145-ton 750-hp. locomotive, has been designed specially for freight service. Interesting data are expected with respect to the performance of this locomotive in service. Up to the present time, the majority of the locomotives are being used in switching service and only a few facts have been obtained with regard to such locomotives in freight service. The report of the Committee on Locomotive Design and Construction, American Railway Association, May 7, 1927, gives some data on a through run with an oil-electric locomotive covering 537 miles with a 377-ton train. These data are reproduced in Table IX.

It will be noted that even in this through main-line service the load factor is only 23.6 per cent.

TABLE XI

OPERATING DATA OF SWITCHING LOCOMOTIVES

Comparison of Internal-combustion and Steam Locomotives

	SERVICE	COST	
	Hours	Per mo.	Per day
Oil Electric, Railroad "A" (*Dec., 1925*)	318	$72.58	2.98
Steam, Railroad "A" (*Dec., 1924*)	297	349.48	14.56
Oil Electric, Railroad "A" (*Jan., 1926*)	380	81.28	3.25
Steam, Railroad "A" (*Jan., 1925*)	315	402.52	14.91
Oil Electric, Railroad "A" (*Feb., 1926*)	293	60.99	2.54
Steam, Railroad "A" (*Feb., 1925*)	295	340.84	14.82
Oil Electric, Railroad "A" (*Mar., 1926*)	442	85.90	3.07
Steam, Railroad "A" (*Mar., 1925*)	300	326.31	12.50
Oil Electric, Railroad "D" (*Feb. 15-17, 1926*)	220	258.30 (est.)	8.61
Steam, Railroad "D" (*Nov., 1925*)	538	1143.90	38.20
Gas Electric, Railroad "E" (*Sept.-Nov., 1925*)	300.4	130.26	5.00
Steam, Railroad "E" (*Sept.-Nov., 1925*)	1509.	517.32	19.90
Gas Electric, Railroad "F" (*Yr., 1925*)	2511.	185.30	7.37

Passenger Service

One of the locomotives in the list presented in Table VII, *viz.*, the 165-ton 900-hp. locomotive, is designed especially for passenger service. From this also interesting data may be expected after it has been in service. At the present time there is available the record of one run of such a locomotive in passenger service. The data are reproduced in Table X.

Operating Costs

The operating costs of oil-electric locomotives, and the comparison of the costs of operation of such locomotives with steam locomotives in the same service, will depend entirely on the operating and service conditions. It would require a very extensive analysis of these conditions before accurate results could be presented. However, the records of a number of results taken under substantially the same operating conditions have been put together as an illustration of the comparative costs of operation of steam and oil-electric locomotives. Table XI is copied from data given in the Report of Committee on Locomotive Design and Construction, American Railway Association, May 7, 1927. This table gives the cost of fuel, lubrication, and water for oil-electric locomotives and for steam locomotives operating in the same yards and as nearly as possible under the same conditions.

TABLE XII

COST OF OPERATION PER LOCOMOTIVE HOUR

Twelve Months of 1928

	Oil-Electric	Steam
Labor	$1.660	$3.310
Fuel	0.365	1.210
Supplies	0.080	0.020
Repairs: Material Labor	0.560	1.070
Enginehouse	0.205	0.795
Depreciation	0.815	0.115
Superintendence	0.895	1.065
Interest	0.505	0.115
Total	$5.085	$7.700
Average saving per hour by the oil-electric locomotive	$2.615	

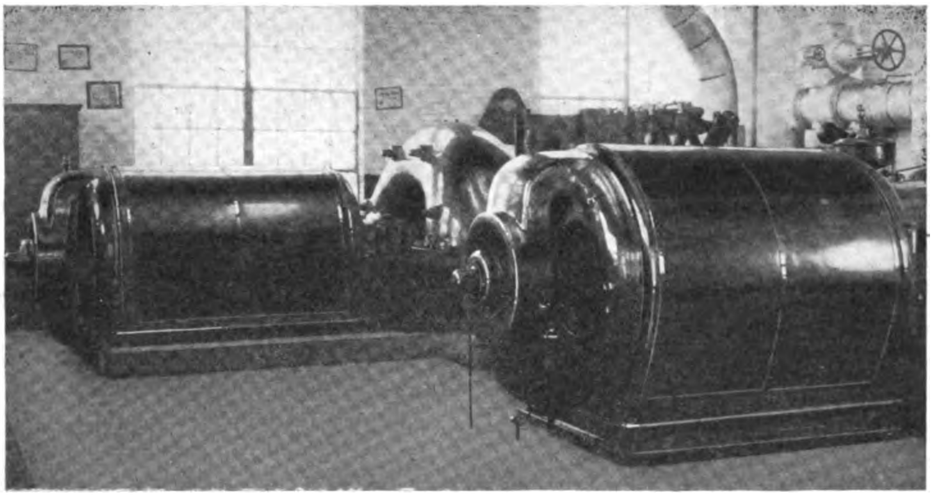
In addition to the comparison given in Table XI, an interesting analysis of the details of such costs is presented in Table XII. This table is taken from a paper by W. L. Garrison, presented before the New York Railroad Club on March 15, 1929, and analyzes the operating cost of a 300-hp. oil-electric locomotive working in a steel-mill yard and the similar cost of a 72-ton steam locomotive which had been replaced by the oil-electric unit.

CONCLUSION

There is without question a wide field open for the internal-combustion engine in railroad service. The success of gas-electric cars in branch-line passenger service makes it evident that the requirements of this service can be met by motor cars, without involving excessive weight or cost of equipment and at an economical operating cost as compared with steam.

It has also been demonstrated that there is a wide field in the low-speed switching service in railroad and industrial freight yards in which the oil-electric switching locomotive can replace the steam locomotive to advantage.

For main and branch-line freight and passenger service, higher train speeds and greater horsepower of locomotive equipments are demanded than are necessary for switching service. Some trial runs have been made on through trains but no very extensive data are available as yet. It is evident, however, that in general the same equipment that has been developed for switching service will be found satisfactory for through service when designed and built for the requisite speeds and horsepower. The work which is being carried on at the present time, and the practical experience which is being obtained with the smaller locomotives, make it probable that within a reasonable time we may expect to see locomotives of the internal-combustion type which will be comparable to main-line steam locomotives in their operating characteristics and in the economy of both first cost and cost of operation.



Automatic Condensing Steam-extraction Type Turbine-generators in an Industrial Plant

Notes on the Resistance of Some Short Conductors of Unusual Shape

By MERTON M. CORY
Associate Professor of Electrical Engineering, Michigan State College

THE resistance of a conductor of uniform cross-section may be obtained by calculation from the physical relationships which are given in the following formula:

$$R=\frac{\text{Length}}{\text{Area}}\,\rho=\rho\,\frac{L}{A} \qquad (1)$$

where ρ is the specific resistance corresponding to the material used and the units involved in measuring L and A.

If we have a conductor, the diameter of which varies as some function of the length, the formula for the resistance becomes more complicated but is readily determined from Equation (1).

For example, take a conductor of any material, the cross-section being a regular polygon of any number of equal sides and with a taper varying as some power of the length, this power being denoted by n in the cases which follow.

From Fig. 1 it is evident that

$$\theta=\frac{360^\circ}{N} \qquad (2)$$

where N is the number of sides, and also that

$$\phi=\frac{1}{2}\left(180^\circ-\frac{360^\circ}{N}\right)=90^\circ-\frac{180^\circ}{N}=\frac{\pi}{2}-\frac{\pi}{N} \qquad (3)$$

The area of each triangle having one side of the polygon as a base and the center of the conductor as the apex is

$$\frac{1}{2}\,bh=r^2\sin\phi\cos\phi$$

where $b=2\,r\cos\phi$

and $h=r\sin\phi$

Hence, the total area of any section is

$$A=N\,r^2\sin\phi\cos\phi \qquad (4)$$

Taking $r=KX^n$ or $X=\left(\frac{r}{K}\right)^{\frac{1}{n}}$ (5)

we obtain the following relations:

$$X_1 : X=r_1^{\frac{1}{n}} : r^{\frac{1}{n}}$$

$$X_1 : X_3=r_1^{\frac{1}{n}} : r_3^{\frac{1}{n}}$$

$$X_1 : X_3-X_1=X_1 : L=r_1^{\frac{1}{n}} : r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}$$

from which it follows that,

$$X_1=\frac{L\,r_1^{\frac{1}{n}}}{r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}} \qquad (6)$$

$$X_3=\frac{Lr_3^{\frac{1}{n}}}{r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}} \qquad (7)$$

$$r=\frac{r_1}{x_1^{\,n}}\,X^n \qquad (8)$$

Taking the first derivative of Equation (1) we have,

$$dR=\rho\,\frac{dL}{A}=\rho\,\frac{dx}{Nr^2\sin\phi\cos\phi} \qquad (9)$$

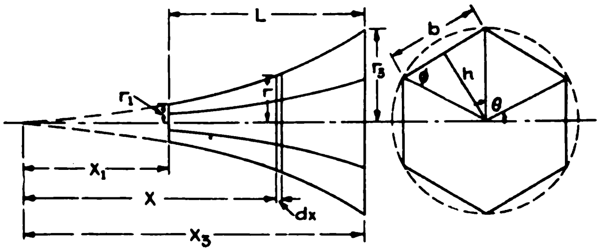


Fig. 1

Substituting the value of r from Equation (8), this becomes

$$dR=\frac{\rho\,dx}{N\left(\frac{r_1}{X_1^{\,n}}\,X^n\right)^2\sin\phi\cos\phi}$$

$$=\frac{\rho X_1^{2n}}{Nr_1^2\sin\phi\cos\phi}\cdot\frac{dx}{X^{2n}}=KX_1^{2n}\,\frac{dx}{X^{2n}} \qquad (10)$$

Integrating both sides of Equation (10) from $R=0$ to $R=R$; and $X=X_1$ to $X=X_3$, we have

$$\int_0^R dR=KX_1^{2n}\int_{x_1}^{x_3}\frac{dx}{X^{2n}}$$

or

$$R=KX_1^{2n}\left[-\frac{1}{2n-1}\cdot\frac{1}{X^{2n-1}}\right]_{x_1}^{x_3}$$

$$=\frac{KX_1^{2n}}{2n-1}\left(\frac{1}{X_1^{2n-1}}-\frac{1}{X_3^{2n-1}}\right) \qquad (11)$$

Substituting the values of X_1 and X_3 from Equations (6) and (7)

$$R=\frac{\rho\left(\dfrac{Lr_1^{\frac{1}{n}}}{r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}}\right)^{2n}}{(2n-1)\,Nr_1^2\sin\phi\cos\phi}\left[\frac{1}{\left(\dfrac{Lr_1^{\frac{1}{n}}}{r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}}\right)^{2n-1}}-\frac{1}{\left(\dfrac{Lr_3^{\frac{1}{n}}}{r_3^{\frac{1}{n}}-r_1^{\frac{1}{n}}}\right)^{2n-1}}\right]$$

$$= \frac{\rho L^{2n}}{(2n-1)\,N \sin\phi \cos\phi\,(r_3^{\frac{1}{n}} - r_1^{\frac{1}{n}})^{2n}} \left[\frac{(r_3^{\frac{1}{n}} - r_1^{\frac{1}{n}})^{2n-1}}{L^{2n-1}} \left(\frac{1}{r_1^{\frac{2n-1}{n}}} - \frac{1}{r_3^{\frac{2n-1}{n}}} \right) \right]$$

$$= \frac{\rho L}{(2n-1)\,N \sin\phi \cos\phi\,(r_3^{\frac{1}{n}} - r_1^{\frac{1}{n}})} \left[\frac{r_3^{\frac{2n-1}{n}} - r_1^{\frac{2n-1}{n}}}{r_1^{\frac{2n-1}{n}}\, r_3^{\frac{2n-1}{n}}} \right]$$

$$= \frac{\rho L}{(2n-1)\,r_1 r_3} \cdot \frac{1}{N \sin\phi \cos\phi} \cdot \frac{r_3^{\frac{2n-1}{n}} - r_1^{\frac{2n-1}{n}}}{r_1^{\frac{n-1}{n}} r_3 - r_1 r^{3\frac{n-1}{n}}} \qquad (12)$$

which is the formula for the cases considered.

For any given radii (r_1 and r_3) and length (L), when N becomes infinity, the perimeter of a section becomes a circle and the resistance a minimum. Substituting this value, $N = \infty$ in Equation (12) results in an indeterminate, therefore to arrive at a usable equation it is necessary to take the first derivative of the right-hand side of Equation (12) and equate it to zero.

Putting Equation (12) in the form

$$R = K \frac{1}{N \sin\phi \cos\phi} \qquad (13)$$

we have

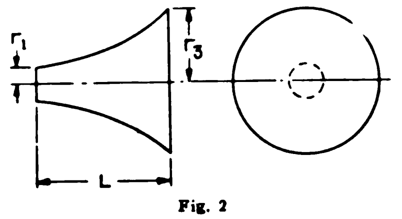


Fig. 2

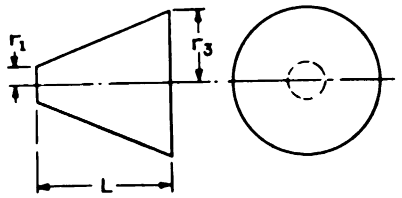


Fig. 3

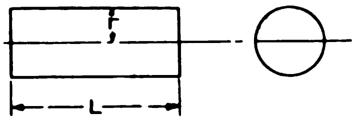


Fig. 4

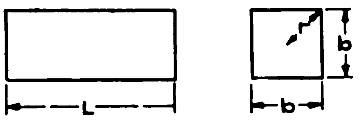


Fig. 5

$$d\left(\frac{K}{N \sin\phi \cos\phi}\right) = \frac{N \sin\phi\, d(\cos\phi)\, d\phi + N \cos\phi\, d(\sin\phi)\, d\phi + \cos\phi \sin\phi\, dN}{N^2 \cos^2\phi \sin^2\phi} \qquad (14)$$

Since $\phi = \frac{\pi}{2} - \frac{\pi}{N}$; $d\phi = \frac{\pi}{N^2} dN$

Equation (14) becomes

$$d\left(\frac{K}{N \sin\phi \cos\phi}\right) = \frac{\left[\frac{\pi}{N}(\cos^2\phi - \sin^2\phi) + \sin\phi \cos\phi\right] dN}{N^2 \cos^2\phi \sin^2\phi}$$

Hence

$$0 = \frac{\pi}{N}(\cos^2\phi - \sin^2\phi) + \sin\phi \cos\phi$$

and

$$N = -\pi \frac{\cos^2\phi - \sin^2\phi}{\sin\phi \cos\phi} \qquad (15)$$

However

$$\cos^2\alpha - \sin^2\beta = \cos(\alpha + \beta)\cos(\alpha - \beta)$$

But $\alpha = \beta = \phi$

then $\cos^2\phi - \sin^2\phi = \cos 2\phi$

and Equation (15) becomes

$$N = -\pi \frac{\cos 2\phi}{\sin\phi \cos\phi} \qquad (16)$$

which substituted back in Equation (12) gives the following as the resistance of a tapered conductor of circular cross-section (Fig. 2):

$$R = \frac{\rho L}{(2n-1)\,r_1 r_3} \cdot \frac{1}{\pi} \cdot \frac{r_3^{\frac{2n-1}{n}} - r_1^{\frac{2n-1}{n}}}{r_1^{\frac{n-1}{n}} r_3 - r_3^{\frac{n-1}{n}} r_1} \qquad (17)$$

If $n = 1$ (Fig. 3) (straight taper), Equation (17) reduces to

$$R = \frac{\rho L}{\pi r_1 r_3} \qquad (18)$$

which is the equation for the resistance of the frustrum of a cone.

When $n = 0$ and $N = \infty$ (Fig. 4), Equation (17) becomes

$$R = \frac{\rho L}{\pi r^2} \qquad (19)$$

the resistance of a cylindrical rod.

When $n = 0$ and $N = 4$ (Fig. 5), Equation (12) becomes

$$R = \frac{\rho L}{2 r^2} = \frac{\rho L}{b^2} \qquad (20)$$

the resistance of a square rod, where r is one-half the diagonal.

The resistivity (ρ) at 20 deg. C., in microhms (millionths of an ohm) per centimeter cube for some of the common metals (*Hudson's Engineers' Manual*), is as follows:

Aluminum	2.83	Mercury	94.1
Copper	1.72	Platinum	9.6
Cast Iron	79–104	Silver	1.62
Steel	12–48	Tungsten	4.9–6.1

Industrial Electric Heating

PART XI: FURNACE ATMOSPHERES (Cont'd)

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SO far in this treatise, the consideration of artificial atmospheres for electric furnaces has been upon the basis of a pressure of one atmosphere, sea level, *i.e.* 14.7 lb. per sq. in., in the heating chamber. In some cases, however, gas reactions are affected by pressure; and there is considerable latitude as to the pressure both above and below one atmosphere—which can be used in heating chambers. It is therefore of interest to know in each case to what extent—if any—pressure affects the reactions with which we are concerned in the use of artificial atmospheres.

Dalton's law of partial pressure states that

$$P_t = p_a + p_b + p_c + \cdot\cdot\cdot\cdot\cdot \qquad (45)$$

in which

P_t = the total pressure in the heating chamber

p_a, p_b, p_c, etc. = the partial pressures of the gases which compose an artificial atmosphere.

For example, if an artificial atmosphere is made up of two active gases, *a* and *b*, at constant temperature the total pressure is

$$P_t = p_a + p_b$$

If now while both the temperature and total pressure are maintained constant there is introduced into this artificial atmosphere a certain portion of an inactive gas *c*, we have

$$P_t = p_a' + p_b' + p_c$$

As P_t is unchanged we thus have reduced the sum of the partial pressures of the active gases, *i.e.*,

$$(p_a' + p_b') = (P_t - p_c)$$

The pressure that is to be considered as regards the effect of pressure on the reactions in a chemical system is the sum of the partial pressures of the active gases, in this case being

$$P_e = (p_a' + p_b') \qquad (46)$$

in which P_e is termed the effective pressure.

Thus in the use of an inactive gas as a diluent in an artificial atmosphere the effective pressure is less than the total pressure by an amount proportional to the percentage of the inactive gas in the artificial atmosphere. In this way, with a total pressure of one atmosphere, we can obtain any effective pressure below one atmosphere that may be desired. If the diluent gas is used for some other purpose than pressure control and if a resulting effective pressure above that which is normal for a total pressure of one atmosphere is required, that value of effective pressure must be obtained by compression.

Avogadro's law states that equal volumes of all gases, under like conditions of temperature and pressure, contain the same number of molecules. Therefore in case of a reaction carried to the end, in either direction, the temperature and pressure conditions remaining unchanged, we can substitute unit volumes for gas molecules in the reaction equation; thus, one unit volume for one molecule, two unit volumes for two molecules, etc. For example, applying these conditions in Equation (26) we can write

$$\underset{\text{2 Volumes}}{2\,H_2O} \leftrightarrows \underset{\text{3 Volumes}}{2\,H_2 + O_2} \qquad (26)$$

That is, considering the direction of the reaction from right to left, two unit volumes of hydrogen and one unit volume of oxygen combine to form two unit volumes of water vapor and hence the reaction product occupies less space than that formerly occupied by the reacting gases.

The fundamental statements in regard to the effect of pressure on gas reactions are:

(*a*). A change in the effective pressure affects the composition of the gas phase of a chemical system if at constant temperature and constant pressure a change in volume is a result of the reaction.

(*b*). An increase in pressure favors the direction of a reaction which results in a decrease in volume and conversely a decrease in pressure favors the direction which results in an increase in volume.

The following table facilitates the location of material hitherto published in this serial:

Part	*Issue*	*Figs.*	*Equations*	*Examples*	*Tables*	*Footnotes*
Part I	Oct. 1927, p. 488	1 to 23	(1) to (8b)	1 to 3	I to III	(1) and (2)
Part II	Nov. 1927, p. 551	24 to 43	(9) and (10)	4 to 6	IV to VII	(3) to (13)
Part III	Dec. 1927, p. 600	44 to 57	(11) and (12)	8 to 11	VIII to IX	(14) and (15)
Part IV	Mar. 1928, p. 125	58 to 73	(13) and (14)	—	X to XX	(16) to (26)
Part V	Apr. 1928, p. 204	74 to 83	(15) to (21)	12 and 13	XXI to XXIII	(27) to (29)
Part VI	Sept. 1928, p. 485	84 to 99	—	14	XXIV to XXVI	(30) to (35)
Part VII	Oct. 1928, p. 560	100 to 113	(22) to (24)	15	XXVII and XXVIII	(36) to (41)
Part VIII	Dec. 1928, p. 662	114 to 138	(25)	—	—	(42) to (47)
Part IX	Mar. 1929, p. 162	139 to 144	(26) to (34b)	—	XXIX to XXXIII	(48) to (59)
Part X	May 1929, p. 278	145 to 150	(35) to (44)	—	XXXIV and XXXV	(60) to (65)

Referring again to the water-vapor reaction, Equation (26), we have from Part IX

$$K_t = \frac{(p_{H_2})^2 \times p_{O_2}}{(p_{H_2O})^2} \qquad (27)$$

The dissociation constant (K_t), in accordance with the general law of chemical equilibria, is constant for a given temperature. If the pressure on the system is changed (within the pressure limits in which the relation of the component gases to simple gas laws is not seriously affected) and the temperature remains constant, the relative percentages of the gases in the system at equilibrium must change. Thus lowering the pressure results in an increase in the percentages of hydrogen and oxygen at equilibrium, *i.e.*, greater dissociation of water vapor. Conversely, raising the pressure decreases the dissociation. This effect of pressure on the dissociation of water vapor is shown in Table XXXVI by Schenck.(66)

TABLE XXXVI
DISSOCIATION OF WATER VAPOR AS AFFECTED BY PRESSURE

TEMPERATURE		PRESSURE IN ATMOSPHERES			
Deg. K.	Deg. C.	0.01	0.10	1.0*	10
		PER CENT DISSOCIATION			
1000	727	1.39×10^{-4}	6.46×10^{-5}	3.0×10^{-5}	1.49×10^{-6}
1500	1227	0.103	4.76×10^{-2}	2.21×10^{-2}	1.03×10^{-2}
2000	1727	2.70	1.26	0.588	0.273
2500	2227	16.60	8.16	3.98	1.95

*The values in this column differ to some extent from the corresponding values in Table XXIX.

The effect of pressure on the dissociation of hydrogen (molecular hydrogen, H_2, into atomic hydrogen, H), is shown in Table XXXVII by Langmuir.(67) At the temperatures with which we are concerned this dissociation is negligible.

TABLE XXXVII
EFFECT OF PRESSURE ON HYDROGEN DISSOCIATION

TEMPERATURE		DEGREE OF DISSOCIATION OF HYDROGEN	
Deg. K.	Deg. C.	Pressure 760 mm. Hg.	Pressure 1 mm. Hg.
1500	1227	0.000002	0.00005
2000	1727	0.0033	0.087
2500	2227	0.0315	0.575
3000	2727	0.13	0.94
3500	3227	0.34	0.993
4000	3727	0.61	0.999

In accordance with Dalton's law the vapor pressures of solids are independent of the presence of other gases; *i.e.*, the vapor pressure of a solid is not affected by a change in the pressure of other gases which may be present in the atmosphere surrounding it. Hence in the case of a reaction in which a solid and a gas participate, the vapor pressure of the solid does not enter into the consideration of the change in volume of the gas at equilibrium—if any—due to the reaction. We have, for example, the reaction of Equation (34):

$$\underset{\text{4 Volumes}}{Fe_3O_4 + 4\,H_2} \rightleftharpoons \underset{\text{4 Volumes}}{3\,Fe + 4\,H_2O} \qquad (34)$$

There being no change in volume in the gaseous reaction products, pressure has no effect on this reaction. From preceding paragraphs it is noted that the water-vapor reaction, Equation (26), is affected by pressure and that reaction is bound up with the iron oxide—hydrogen reaction, Equation (34). Now since the dissociation constant (K_t) of Equation (27) does not vary with change of pressure and since the equilibrium constant (η_t) of Equation (33) and Fig. 144 involves the quotient of the dissociation constant (K_t) by the fixed value of the oxygen pressure above an oxide, the equilibrium constant (η_t) is not affected by pressure at any temperature. Hence we have for the iron oxide—hydrogen reaction, Equation (34).

$$\left[\frac{K_t}{p_{O_2}}\right]^{\frac{1}{2}} = \eta_t = \frac{p_{H_2}}{p_{H_2O}}$$

$$= \text{a constant quantity at temperature } (t) \text{ for any pressure.}$$

This was investigated experimentally by Preuner(68) who found that at various temperatures there was no change in the equilibrium constant due to change in pressure.

We have the same result as regards the effect of pressure on the iron oxide—carbon monoxide reaction of Equation (38), *viz.*,

$$\underset{\text{4 Volumes}}{Fe_3O_4 + 4\,CO} \rightleftharpoons \underset{\text{4 Volumes}}{3\,Fe + 4\,CO_2} \qquad (38)$$

That is, this reaction is unaffected by pressure.

Hence in the use of either a hydrogen atmosphere or a carbon monoxide atmosphere—or an artificial atmosphere composed of a mixture of these two gases—as an agent for the reduction of a metallic oxide by heat, we neither gain nor lose as far as these reactions are concerned by varying the effective pressure.

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(66) *The Physical Chemistry of Metals*, p. 158, John Wiley & Sons, Inc.

(67) "The Dissociation of Hydrogen Into Atoms," *Jour. Amer. Chem. Soc.*, Vol. 37, p. 417.

(68) "The Equilibrium Between Iron, Iron Oxide, Hydrogen and Water Vapor," *Zeit. fur Phys. Chem.* Vol. 47, p. 385.

The methane reaction which is attendant on the iron oxide—hydrogen reaction shows a change of volume due to the reaction thus;

$$\underset{\text{1 Volume}}{CH_4} \leftrightarrows \underset{\text{2 Volumes}}{2\,H_2}+C \qquad (35)$$

Hence this reaction is affected by pressure, an increase in pressure favoring the formation of methane. At equilibrium, at temperature *t*, with the constant value of the vapor pressure of pure carbon we have from Equation (37).

$$\frac{K_t}{p_C} = \eta_t = \frac{(p_{H_2})^2}{p_{CH_4}}$$

= a constant quantity at temperature *t* for any pressure.

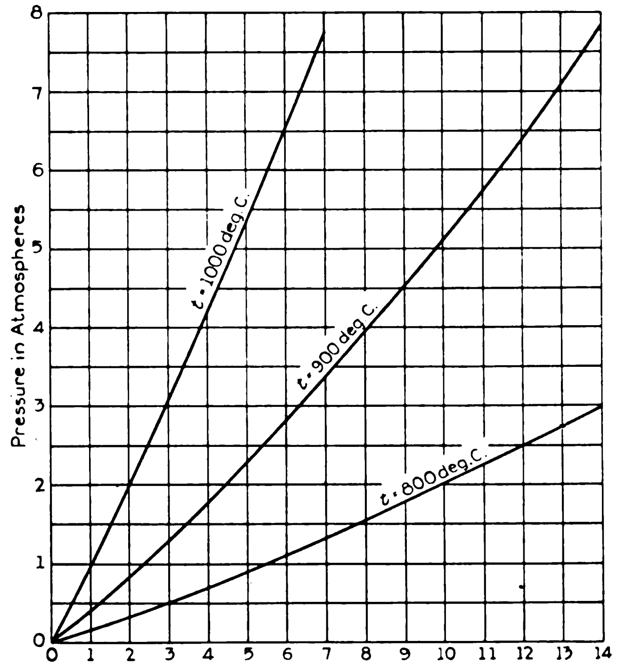

Fig. 151. Equilibrium Curves for the Reaction $CH_4 \leftrightarrows 2H_2+C$

Here we note that the fraction—or ratio—$\frac{(p_{H_2})^2}{p_{CH_4}}$ involves an exponent in the numerator which is different from the exponent of the denominator. Therefore, although the value of the equilibrium constant (η_t) is not affected by pressure, the actual relative percentages of hydrogen and methane in the system are affected by pressure.

For this system, as represented by Equation (35) at equilibrium with pure carbon at temperature *t*, let

x = the volume percentage of methane

then

$(100-x)$ = the volume percentage of hydrogen.

Let P = the total pressure

then

Px = the partial pressure of methane

$P\,(100-x)$ = the partial pressure of hydrogen.

Substituting these quantities in Equation (37) we have

$$\eta_t = \frac{P\,(100-x)^2}{x} \qquad (47)$$

and

$$P = \frac{\eta_t\, x}{(100-x)^2} \qquad (48)$$

This last expression is the equation of the equilibrium curve, *i.e.*, the relation of pressure and percentage of methane in the system at equilibrium with pure carbon at temperature *t*. Equilibrium curves(69) for 800, 900, and 1000 deg. C. are given in Fig. 151. These isotherms show graphically the effect of pressure on the methane reaction—Equation (35)—and hence represent the effect of pressure on the decarburization of steel and, conversely, on the carburization of steel by methane for the temperatures noted. Thus in the heat treatment of steel in a hydrogen atmosphere the effect of increasing the pressure is an increase in decarburization; or if there is an excess of methane in the system, carburization is increased by lowering the pressure. In either case the effect of pressure change is but little affected by temperature.

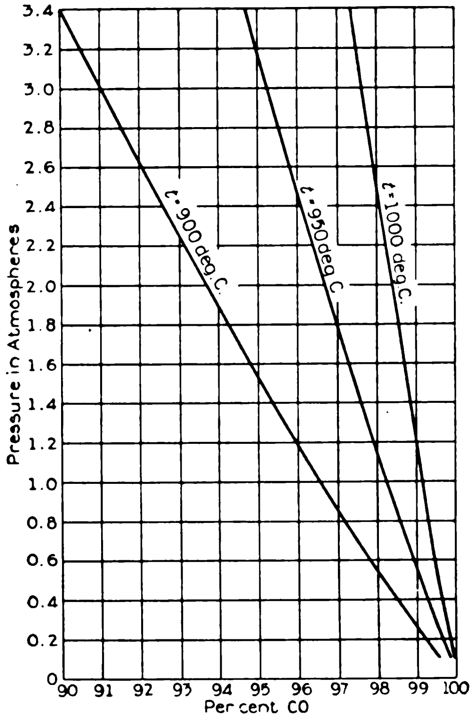

Fig. 152. Equilibrium Curves for the Reaction $2CO \leftrightarrows CO_2+C$

If the heat treatment of steel is carried on in an atmosphere of carbon monoxide in accordance with Equation (38), the attendant reaction, *viz.*,

$$\underset{\text{2 Volumes}}{2\,CO} \leftrightarrows \underset{\text{1 Volume}}{CO_2+C} \qquad (42)$$

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(69) NOTE.—The value of the equilibrium constant (η_t) for a given temperature is obtained by substituting in Equation (47) the value of x for that temperature (from Fig. 145 for which $P=1$ atmosphere). This value of η_t is then substituted in Equation (48) together with various assumed values of x to obtain corresponding values of P in fractions or multiples of one atmosphere.

shows that an increase in pressure favors the formation of carbon dioxide. Here we follow a similar procedure as in case of the methane reaction of the preceding paragraphs.

Let $x =$ the volume percentage of carbon monoxide in the system at equilibrium with pure carbon at temperature t.

Then $(100-x) =$ the corresponding volume percentage of carbon dioxide

Let $P =$ the total pressure

then $Px =$ the partial pressure of carbon monoxide

and $P(100-x) =$ the partial pressure of carbon dioxide.

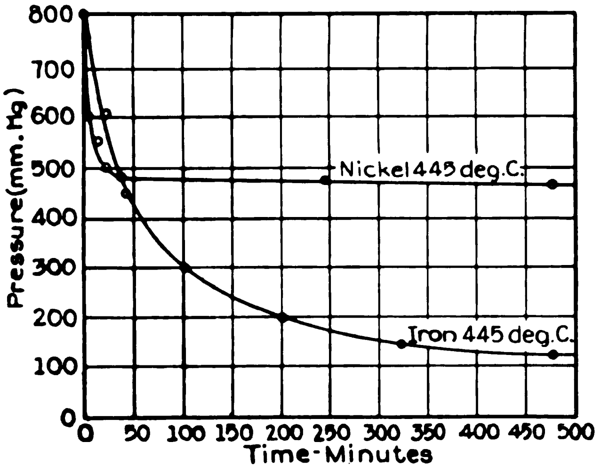

Fig. 153. Change of Pressure with Time Occurring in a Given Amount of Carbon Monoxide at Constant Volume During the Dissociation Reaction in the Presence of Nickel and Iron (*Schenck*)

Substituting the above in Equation (44) we have,

$$\eta_t = \frac{(100-x)}{Px^2} \tag{49}$$

and

$$P = \frac{(100-x)}{\eta_t \, x^2} \tag{50}$$

Equation (50) is the equation of the equilibrium curve, *i.e.*, the relation between pressure and percentage of carbon monoxide for the reaction of Equation (42) in equilibrium with pure carbon at temperature t. Equilibrium curves(70) for 900, 950, and 1000 deg. C. are given in Fig. 152. For this reaction we have at constant temperature a decrease in the percentage of carbon monoxide in the system (at equilibrium with pure carbon) as the result of an increase in pressure, and conversely, an increasing percentage of carbon monoxide with a lowering of the pressure.

Our first interest in this effect of pressure depends upon the object for which the carbon monoxide atmosphere is used. If the process is the reduction of iron oxide by heat it is necessary to keep the percentage of carbon dioxide in the artificial atmosphere below the equilibrium value for the temperature of the process, as shown in Fig. 149. To this end a lowering of the pressure is advantageous. If the carbon monoxide is used as an agent for carburization of iron an elevated pressure is an advantage.

In both the cases cited of the effect of pressure on attendant reactions in the heat treatment of steel it is to be kept in mind that the vapor pressure of carbon in solution in iron is measured by the degree of carbon saturation. Thus in carburizing, for example, the effect due to a higher or a lower pressure, as the case may be, diminishes as the carbon saturation point for the particular temperature is approached.

The carbon monoxide reaction of Equation (42) depends upon the presence of a catalyst such as iron or nickel. The behavior of the reaction with nickel as the catalyst is what we would expect from the consideration of the volume relation of this reaction, *i.e.*, at constant temperature and constant volume the reaction would proceed to the right until the pressure fell to one-half the original pressure. This is shown by Schenck(71) in the chart given in Fig. 153. With iron as the catalyst, as would be the case in the heat treatment of steel, the carbon dioxide formed may increase the percentage of carbon dioxide in the system above the equilibrium value for the temperature of the process as shown in Fig. 149. This would result in the formation of iron oxide. Here then we may have two simultaneous reactions; oxidation, forming a solid product; and dissociation of carbon monoxide, also forming a solid product. These effects are cumulative and lower the pressure below that indicated by the volume relation of the reaction. This is also shown in Fig. 153 by Schenck. Hence, as noted in Part X, we may have oxidation of iron in a carbon monoxide atmosphere, another illustration of a previous statement that the terms oxidizing, neutral, and reducing as applied to a furnace atmosphere must be accompanied by reference to the conditions of equilibrium in each case. In practice, if we are free to control the artificial atmosphere, this interference with the function of a carbon monoxide atmosphere is avoided by preventing the accumulation of carbon dioxide in the system.

Nitrogen has been referred to as a so-called inactive gas. For many heat treatment processes nitrogen is inactive or not sufficiently active to be objectionable and can be used as a diluent in artificial atmospheres. An important exception is the use of this gas for the surface hardening of steel, the nitriding process.

Argon and helium are inactive gases with respect to all metals at all temperatures and pressures with which we are here concerned. Exceptions to this broad statement may develop as more experience is obtained with the use of these gases as diluents in artificial atmospheres.

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(70) NOTE.—The value of the equilibrium constant (η_t) for a given temperature is obtained by substituting in Equation (49) the value of x for that temperature from Table XXXV; for which $P=1$ atmosphere. This value of η_t is substituted in Equation (50) together with various assumed values of x to obtain corresponding values of P in fractions of or multiples of one atmosphere.

(71) *The Physical Chemistry of Metals*, p. 171, John Wiley and Sons, Inc.

Steam is an inactive gas. However, as previously noted, steam is subject to dissociation. The extent of this dissociation under different temperature and pressure conditions is given in Table XXXVI. Steam may also—and usually does—carry entrained oxygen from the air in the water from which the steam was made. (If the water is deaërated this, of course, does not apply). The entrained oxygen—if any—and the oxygen produced by dissociation govern the use of steam as an artificial atmosphere. We have already noted the reaction of water vapor and iron in Equation (34). Hence, because of this reaction steam is not suitable as an artificial atmosphere for the heat treatment of iron and steel. Steam is well adapted as an inactive artificial atmosphere for the heat treatment of non-ferrous metals and their alloys for the prevention of oxidation, as in bright annealing.(72) Here we have the requirement that the partial pressure of the oxygen in the atmosphere must be less than the partial oxygen pressure of the oxide of the metal. Assuming that there is no entrained oxygen in the steam, by reference to Table XXXVI we find that despite the decreased dissociation of the steam with an increase in pressure the partial pressure of oxygen increases with an increase in the total pressure. Hence an increase in pressure is disadvantageous, but is permissible up to the point at which the partial pressure of oxygen becomes equal to the partial oxygen pressure of the oxide of the metal or alloy which is the subject of the heat treatment process. On the other hand by decreasing the pressure we have the reverse condition, that is, despite the increased dissociation of the steam the partial pressure of oxygen in the gas mixture is lowered. Hence as far as prevention of oxidation of non-ferrous metal or non-ferrous alloy is concerned, there is no gain by an elevated pressure and there is an advantage in operating at as low a pressure as conditions will permit. If there is entrained oxygen present in the artificial atmosphere, the maximum permissible pressure in a given case is lowered to the extent that the entrained oxygen is present; and the lower the operating pressure the more the permissible entrained oxygen.

Mixtures of active gases, whether mixtures of selected gases or the mixtures peculiar to a gaseous product such as natural gas and manufactured gas, are suitable for artificial atmospheres and may often be better suited to a given purpose than a single gas.

The analysis of both natural gas and of manufactured gas vary, according to the location in the first case and according to the method of manufacture in the case of manufactured gas. Typical analysis of a natural gas and of manufactured gas are given in columns *A* and *B* respectively of Table XXXVIII.

The reference in Part X to a use of natural gas as the source of methane for carburization by Sykes(55) is an example of the use of a natural-gas artificial atmosphere. This use of methane is also of value in preventing decarburization of steel by hydrogen when the latter gas is used as an artificial atmosphere.

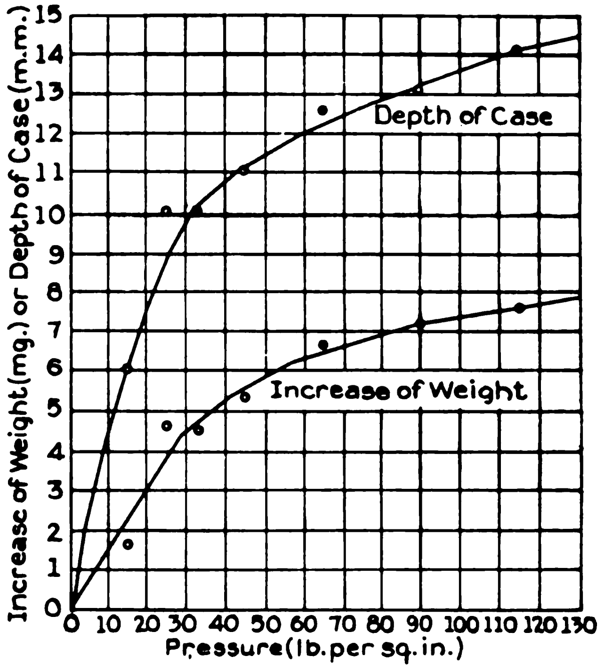

Fig. 154. Pressure-penetration Curves for a Gas Carburizing Process Taking Place at a Temperature of 910 Deg. C.
(*Sauveur*)

Sauveur(73) gives a record of the effect of pressure on carburizing iron, using manufactured gas of the composition given in column *B* of Table XXXVIII. The temperature was 910 deg. C. The chart of Fig. 154 is from this reference. It will be noted that the knee in each of the curves occurs at a pressure of about 40 lb. per sq. in. From the analysis of the gas used it is seen that the main sources of the carbon

TABLE XXXVIII
TYPICAL GAS ANALYSES

Gases	PER CENT	
	A	*B*
Hydrogen	....	40.10
Methane*	83.5	26.10
Nitrogen	3.8	14.04
Carbon Dioxide	0.2	1.64
Oxygen	....	0.58
Carbon Monoxide	....	11.38
Ethane	12.5	....

*Usually the principal constituent of natural gas, ranging according to location from 70 to 95 per cent.

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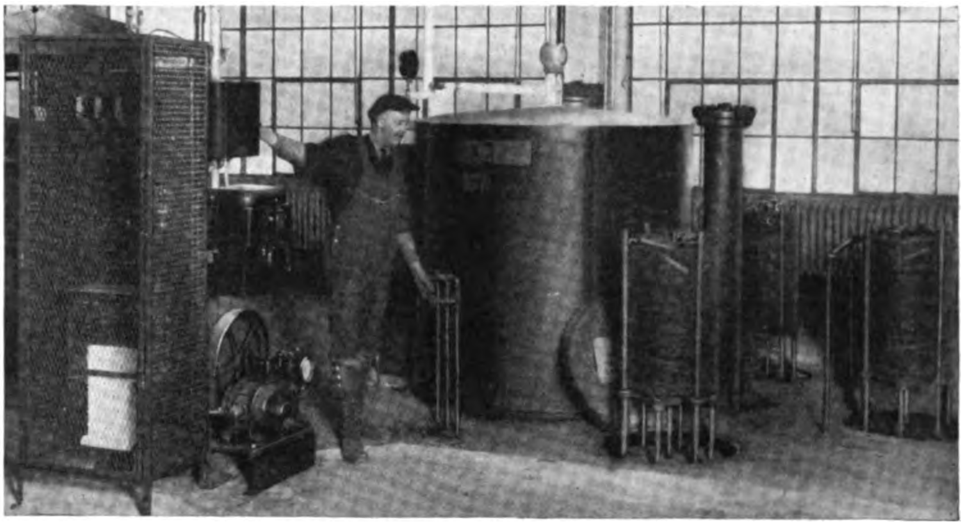
(72) Bright annealing: The annealing of a metal or alloy without discoloration by oxidation.

(73) *The Metallography and Heat Treatment of Iron and Steel*. 2d Ed. p. 319.

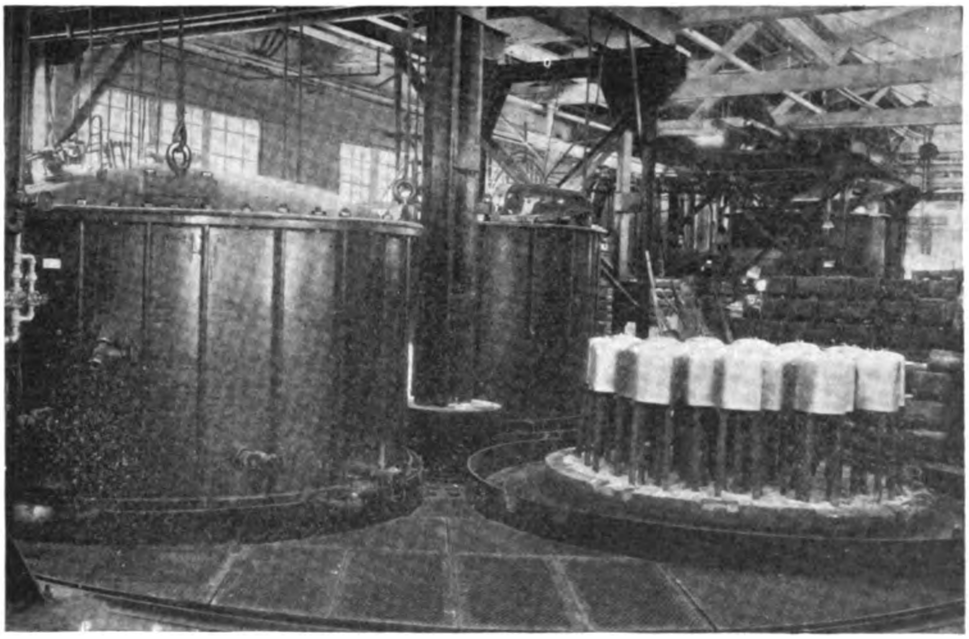
were methane and carbon monoxide. In the case of methane the rise in pressure operated adversely to carburization (see Fig. 151); while with the carbon monoxide the increase in pressure was favorable to carburization (see Fig. 152). The joint effect of these two opposing pressure effects, together with the effect of the increasing vapor pressure of carbon in solution in iron, served to produce a resultant effect of pressure on carburization as exhibited by the chart.

We may also use Fig. 154 to point out that while in the foregoing discussion of gas reactions we have to a large extent considered the reactions individually we must in practice consider the joint effect of all reactions in the chemical systems with which we are concerned in each case. This joint effect is not subject to analysis, save to a limited extent; and in the end the selection of an artificial atmosphere of mixed gases for a given purpose must be by trial guided by an understanding of the individual reactions.

(*To be continued*)



Small Furnace for Bright Annealing Small Copper Parts



Three-stage Brazing Furnace for Copper-brazing Steel Parts Together

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Electrical Engineering Economics. D. J. Bolton. 305 pp., 1928, Lond., Chapman & Hall.

English and Science. Philip B. McDonald. 186 pp., 1929, N. Y., D. Van Nostrand Co., Inc.
(Recognizing the special needs of the technical professions for precision and lucidity of thought and expression, the author of this useful and exceedingly interesting book has clearly stated and illustrated the principles of good writing. This he has accomplished, in a positive sense, by indicating the means of expression through proper sentence structure and well-chosen words, besides pointing out common faults: obscurity, pomposity, ornateness, and the ever-present marks of amateurishness. The book, however, is more than a mere guide to good writing because it suggests a proper evaluation of the influences and tendencies that appear in our complex social system of the present, and perhaps points the way to a culture not heretofore attained.)

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Practical Railway Painting and Lacquering. H. Hengeveld. C. P. Disney, and William J. Miskella. 242 pp., 1929, N. Y., Simmons-Boardman Pub. Co.
(This is the fourth volume of the "Practical Finishing Series" sponsored by the Finishing Research Laboratories, Inc., Chicago. It is indicated as being "A Handbook for Railroad Men," a statement which is well borne out by its practical nature. The authors are men of long experience, two of the three being railway men actually in charge of painting operations. The twenty-seven chapters are grouped into five parts "General Information," "The Painting and Lacquering of Locomotives, Freight and Passenger Cars," "The Painting of Signal Equipment," "The Painting of Bridges, Buildings and Water Service," and "The Lacquering of Electric Railway Cars." The many illustrations of equipment and methods, and the numerous tables of data add materially to the usefulness of the text. An adequate index is provided.)

Radio Receiving Tubes. James A. Moyer and John F. Wostrel. 297 pp., 1929, N. Y., McGraw-Hill Book Co., Inc.

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(The author states that he has endeavored to set forth, in this 35th annual edition of his standard work, "the essential requirements for safe and efficient wiring and construction for electric light, heat and power, in accordance with the National Electrical Code, and the latest engineering practice." Those who have had occasion to use earlier examples of this same work will remember that it is essentially a handbook of practical information for those called upon to actually install electrical wiring and electrical devices. This most recent edition presents new special sections on the national "Red Seal Plan" for residence wiring, and on the "Franklin Specification" for commercial wiring.)

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Theory of Heat Engines. Ed. 3. William Inchley. 504 pp., 1929, N. Y., Longmans, Green & Co.

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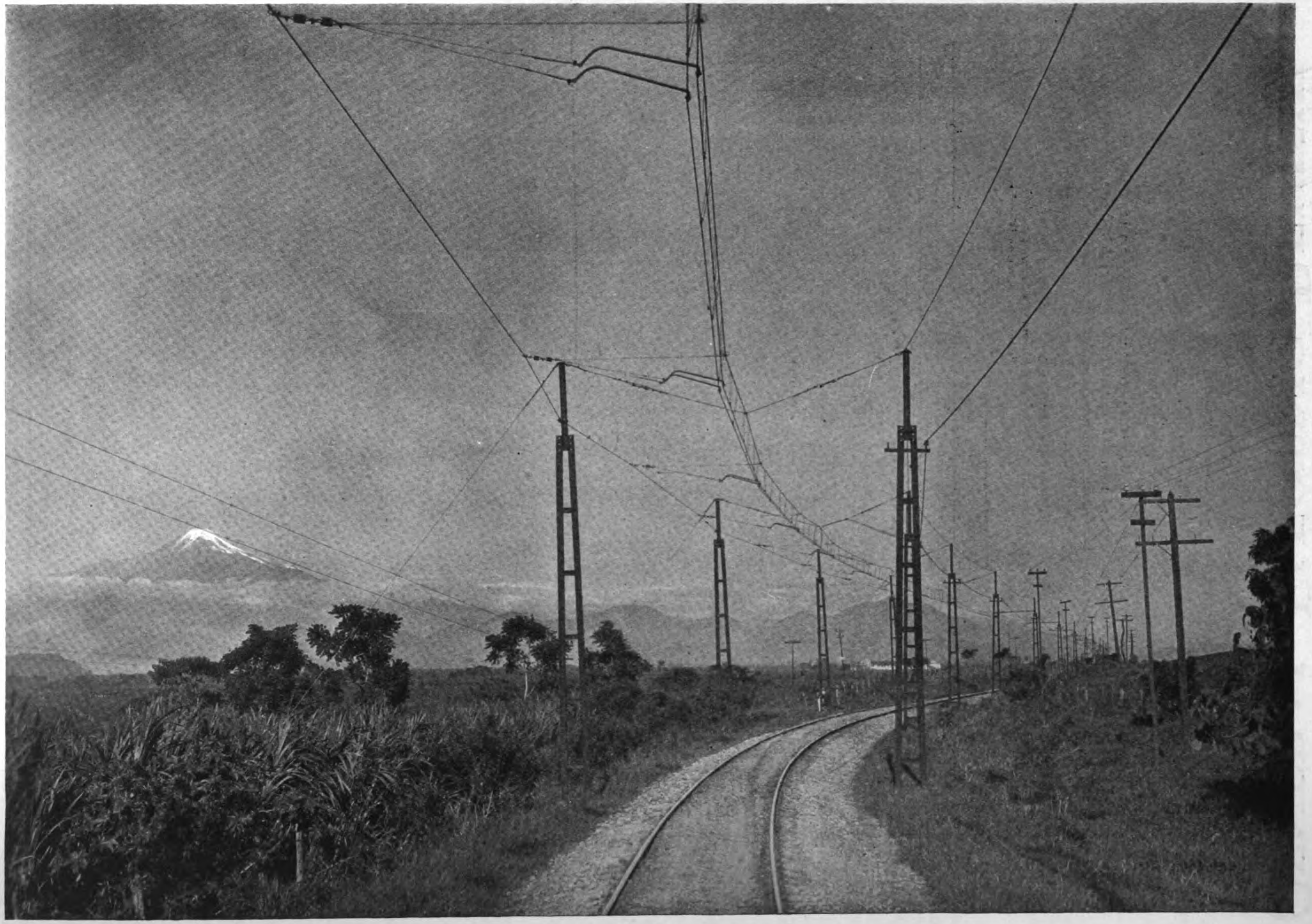


INTO THE HILLS OF OLD MEXICO

A view on the electrified section of the Mexican Railway just below Cordoba. In the distance is Mt. Oriza'ba, which is the second highest peak in North America. The poles along the right-of-way were the first to be fabricated from discarded track rails. For single-track sections the distribution system shown is typical, there being a positive feeder with a smaller negative feeder above it to supplement the rail return and also to serve as ground-wire protection against lightning. (*See p. 504*)

GENERAL ELECTRIC
REVIEW

Vol. 32 September, 1929 No. 9

PEACE

To us it seems to be an extraordinarily fortunate coincidence that the great privilege of proclaiming to the world at large that the very basis of international law had been revolutionized, by the voluntary action of some forty nations, should have fallen to the lot of the first engineer President of the United States.

We refer to an act, without parallel in history, which occurred at 1:22 o'clock on the afternoon of July 24, 1929, in the White House at Washington, when President Hoover announced that the Briand-Kellogg Pact—renouncing war as a national policy, and pledging the settlement of disputes by peaceful means—was in force.

Our lives themselves, our conduct one toward the other and the relationship that one nation assumes toward the other nations of the earth, are actualities, and, as such, can be changed by the increasing light of intelligence; and can, and should be, governed by wisdom and the power of reason rather than by greed and passion.

It would be exceedingly easy to write a lot of platitudinous humbug about the sin and horror of war and the virtue and blessing of peace. But we are going to do nothing of the kind. We would rather state frankly that, as we interpret the past, we believe some of the finest characteristics of the human race have been achieved by war. We will also state frankly that we believe that the day has now arrived when war is useless.

To all those doubters, who see but a thin shadow of a moral hope in this great pact, we would say that but a short time ago we numbered ourselves with them, but, that today, with a greater faith in the evolution of the intelligence of mankind, we believe that it is possible and practical to outlaw war.

The preaching alike of the doctrine of peace and the possibility of peace has been left too often, and too long, to the weak-kneed rather than to the strong-minded, and to that great class of talkers and writers who had their wishbones more highly developed than their backbones.

The first requisite to make this great international pact—that the most powerful civilizations of the world have signed and sealed—bear the desired fruit, is strong, understanding, and able leadership in showing the intelligent people in every land that the thing undertaken is both possible and practical. It is. And where could a stronger, better, or more able leader be found than in him who so recently proclaimed it to the world?

Whether the work on hand is a success or a failure, depends upon whether the intelligent people of the world take a positive or a negative view of the matter. The task is to make them take a positive view.

This task can best be achieved by making the people realize that new conditions are constantly being created, and that the past shall not always govern the present and the future, and that we are living in a new world.

Man has reached the stage of being an intelligent, thinking, reasoning creature only for an incredibly short time. Fighting the elements, and against the wild creatures with less cerebral cortex than himself, and against his fellow man has been a factor in training him in his earliest schoolroom, and has been a potent factor in making man what man is. But we believe intelligent man has reached a stage today where he can be brought to see that the time has passed when there is either useful purpose or profit in man fighting man.

We hope that the old-fashioned statesmanship of the past is as bankrupt as it was corrupt. The masses in many countries today are, fortunately, too intelligent and too well educated to permit blundering politicians taking the poorest and the most ignorant of their number by the hundreds and the thousands, dressing them up in uniforms, and shipping them off to kill their fellow human beings, whom the more often they know nothing about, and who, if they did know, would be more likely to be their friends than their enemies.

In olden days there used to be something chivalrous, something glorious, and something romantic in war, but you can't be chivalrous with machine guns, high-explosive shells, and torpedoes, and there is neither glory nor romance in trench and submarine warfare.

Those same scientists, engineers, and inventors that have given us a new and modern world have also taken the romance and chivalry from war and made of it a double-distilled hell on earth.

The invention of gunpowder did much to deprive war of its chivalry and glory, and to take away the chance of performing those old picturesque acts of personal bravery in battle, as it also did much to dethrone despotism and tyranny. But even after the advent of the rifle and the cannon some of the intoxication and glamour of war was cunningly maintained —but not on the battle field.

There were still the smart uniforms and intoxicating music—the beating of the drums, the shouts of "Here they come," and the blare of the trumpets, the high, shrill notes of the fife, the tramp, tramp, tramp of the marching host, the cheers as the national flag was borne proudly by, and the thrill in every heart as some famous, much honored, and well-beloved regiment, with history to its name, marched forward and was greeted with the well-earned hurrahs of an excited and enthusiastic crowd.

Then in the evening—and far into the night—there were still the many drinks stood—not wisely but too well. The fetish of the uniform, the rapid succession of servant girl—and other—lovers. The thrilling, if brief, romances, and finally the sympathy for war babies.

Yes, there is even still some glory and romance in the streets and on the pavements of our capital cities, and in every town, village and hamlet in the land when war is declared. But Cupid is doing the shooting there, and is doing it with his old-fashioned bow and arrow. But the crowd that thrills and is thrilled is also the crowd that is duping and is duped. They see the making of an army; not the breaking of the army. They see the glory; not the gore. They see the life; not the death. They see the living; not the dying. Science and engineering have taken the last traces of glory and romance from war on the battle field.

Read every heroic war poem that has ever been written. View every war picture that has ever been painted, and if they are picturesque and beautiful, they are portraying the battles of the past—not the present.

Where is the picturesqueness in cold, damp, water-sodden trenches? Where is the romance in being blown to pieces by the chemist's latest invention in high-explosive shells, or in inhaling his newest poison gas? Where is the chivalry in charging a battery of machine guns? Are airplanes and Zeppelins, dropping bombs on babies, pretty things? The slaughter of women and children, young men and maidens, grandfathers and grandmothers, and the destruction of homes, from the skies, is but one of science's many contributions to modern warfare!

There was romance at sea when the old ships, well beloved, with their sails full-bellied with the wind, and their decks upon decks of muzzle-loading guns, sailed into action—fired their broadsides—and grappled with the enemy. There were hearts of oak in ships of oak in those days. But is there the same romance in a squadron of modern battle cruisers with guns of larger range, and with engines of greater power and higher speed meeting an enemy and standing out of range themselves, while sinking the enemy's ships of lesser caliber?

There is nothing chivalrous or brave in torpedoing an unarmed merchantman and sending non-combatant men, women, and children to a watery grave, and in scalding, burning, and drowning the engineers and stokers like vermin in a cage. It may all be scientifically efficient but it is an abomination in the eyes of humanity.

The scientists and engineers have made a hell on earth of war—they have destroyed the chivalry, stolen the glory and killed the romance, and we feel now that the time has arrived for them to use their highly developed brains in taking the lead in teaching the world that war can be outlawed.

We believe there used to be a purpose in war, but now that, practically speaking, the entire surface of the earth has been discovered and explored and the most desirable parts settled by man and the absurdity of fighting over religion is recognized, we believe that war has lost its purpose. Now that man has become an industrious creature, and, by science, engineering, and invention has proved, in certain regions of the world, what may be done for all lands and for all people by using the resources of nature in the service of mankind, we all know that his time is better spent in the pursuit of peace than in the pursuit of war.

What land could be taken as a better example than the United States of America for those that have the will and intelligence to review the accomplishments of the last one hundred years?

The scientist and the engineer (throughout we use this term in its broadest meaning, including all constructive individuals) have made a new world out of the old world and they have done it by everlastingly finding and using new means of converting the natural products of the earth into serviceable commodities.

The instant war is declared their energies are diverted from the path of construction into the channels of destruction. It is for them to settle which path they wish to pursue in the future. It is because we believe so strongly in the increase of wisdom, and in the evolution of human intelligence, that we also believe the constructive brains of today have arrived at the stage where they can teach the world that war can be outlawed. It is too costly.

There are some, we know, that think that man can only progress to a certain point in building up his civilizations and that after a period of disaster and destruction, he must start anew. We do not hold that view. We believe that there are sufficient intelligence, wisdom, and common sense in the world today that with able leadership, the entire world can be brought to see that war is useless. The increased cost of modern warfare and the increase in the destruction of human lives and of property and the asinine procedure of holding a peace conference after the damage and destruction is done rather than settling the dispute by peaceful means beforehand should convince all people of the virtue in the Briand-Kellogg pact.

Every one must fight if we have another war. The fighting won't be only on the battle fields. There will be fighting on the land and on the sea and in the skies. It will be carried right into the homes of the peoples. Every one will fight—and every one will lose. The cost would be unthinkable, and part of the price might be our civilizations. Even the victors must lose in modern warfare.

The Napoleonic wars (1790-1815), a conflict that lasted 9000 days, killed 2,100,000 human beings, and cost $3,070,000,000.

The American Civil War (1861-1865) lasted 1350 days, cost 656,000 lives and $7,000,000,000.

The Franco-Prussian war (1870-1871) lasted for 210 days and cost 280,000 lives and $3,210,000,000.

The Russo-Japanese war (1904-1905) lasted 548 days, cost 160,000 lives and $2,100,000,000.

The above figures are for wars of the recent past, but how they pale before those of the World War!

The World War (1914-1918) lasted 1563 days, cost 9,818,000 lives and $186,233,637,097.

Now, all the real property in the United States, from the Canadian border to the boundaries of Mexico, and from the Atlantic to the shores of the Pacific Ocean, are worth considerably less than the cost of the World War.

It should interest and impress all engineers, business men, and all other people with common sense to learn that all the steam railroads and their equipment, all the motor vehicles, all the street railways, all the telegraph systems, all the telephone systems, and all the electric light and power stations of the entire United States of America could be purchased for a sum of money considerably less than one-quarter of the cost of the World War.

We have been told that of all the moneys raised from the peoples of the earth in taxation, eighty cents out of every dollar goes to defray the costs of the wars of the past and in the preparation of future wars. The thing is absurd.

We are always optimists. We realize in some measure what man has done for man since his constructive genius has been encouraged rather than suppressed. We believe in the evolution of intelligence and in the power of education and of work. What man has done in the past is as nothing to what he can, and will, do in the future. If he spends all his energies in peaceful pursuits the wonders of the new world that he is building will eclipse the wildest dreams of the most fantastic fairy stories.

Most of the wars of the past have been fought over religious prejudices and for the conquest of territory. Both should be old-fashioned in our modern world. The chief cause for strife in the future, however well the facts may be disguised, is likely to be for the markets of the world. Today these problems can be better and more economically settled around the conference table than on the battle field. Fear, suspicion, and ambition, the breeders of war, can best be subjected to the rule of wisdom and reason by a common-sense honest-to-all limitation of armaments.

We are not pacifists nor are we preaching pacifism, but we do believe that patriotism may well expand its scope and be better satisfied in destroying poverty and in taking a justifiable pride in improving the living and working conditions of the people, and in bringing about a more equitable distribution of wealth, both nationally and internationally, than in vainglorious boasting and declarations of superiority.

If the first engineer President of the United States were to propose to the world at large that each nation spend a sum of money, a small fraction of their annual expenditure in the preparation for war, in educating their people as to what the Briand-Kellogg pact may, and should mean to the world, we believe that the signatures on that great document will remain forever honored.

If the first engineer President of the United States should ask every nation in the world to declare July 24 the first great international holiday, and to dedicate it to declaring anew to every man, woman, and child in the world that on July 24, 1929, the great nations of the earth outlawed war, we believe they could be educated into the path of peace rather than into the ways of war.

In the future we can have either peace or war. It depends upon what the peoples believe. Some one must lead in educating them. J. R. H.

Electric Locomotive Availability

WITH SPECIAL REFERENCE TO THE BUTTE, ANACONDA & PACIFIC RY.

About 98.5 Per Cent After 16 Years of Service—Operating Conditions Severe—Locomotives Have Not Required a General Overhauling—Elaborate Inspection and Shop Facilities Unavailable

By F. W. BELLINGER
Electrical Superintendent, Butte, Anaconda & Pacific Railway

There are two types of availability: that in which the device remains in constant readiness to serve but is inert until actually called upon to function at infrequent intervals, as is characterized by the service of a lightning arrester. The type of availability with which we are more commonly concerned however is that of the machine, represented here by the electric locomotive with its enviable record despite severe service conditions.—EDITOR

THE statement that electric locomotives can be kept in service a much greater percentage of the time than can steam locomotives is not conclusive unless the statement is substantiated.

It is unfortunate that exact data on the availability of steam and electric locomotives are not to be had on the majority of roads. Because of its importance, information on the subject has been compiled to show the status regarding availability of the Butte, Anaconda and Pacific locomotives. Due consideration has been given to the various factors which enter into the problem.

A brief history of this railroad, together with a statement regarding general operating conditions will furnish a mental picture of this railroad. The Butte, Anaconda & Pacific Railway was built in the year 1892, principally for transfer service between the ore mines in Butte and the smelter in Anaconda. The trackage, including yards and sidings, brought the total mileage up to approximately 90 miles. In 1912 these tracks were electrified. Since that time the electrification has been extended until at present 123 miles are electrified.

Economy

Unlike many electrification projects, the B. A. & P. was electrified for economic reasons only. This was the exception rather than the rule at that time. Practically all electrifications prior to 1912 came into existence primarily for the purpose of overcoming some special condition, such as tunnel limitation, congested territory, or smoke nuisance. This road was the first to make use of 2400 volts direct current for main-line propulsion purposes. That the management's judgment was sound in changing from steam to electric power is evidenced by the splendid results obtained.

Operation

Last year, 28 locomotives, most of which were in switching service, totaled 700,874 miles divided as shown in Table I.

TABLE I

Passenger....	5.51 per cent	Freight....	48.38 per cent
Switching....	45.99 per cent	Work.....	0.12 per cent

In connection with this mileage, 248,085,908 gross ton-miles were handled, exclusive of locomotive and caboose. The power metered to the motor-generator sets averaged 69.9 kw-hr. per 1000 ton-miles.*

Availability

The accompanying figures of electric locomotive availability, Table II, have been taken from the records of January, February, March, and April of this year, and are representative of the past performance of this equipment. The months of January and February represent winter conditions.

TABLE II
COMPUTATION OF AVAILABILITY

	January	February	March	April	Four Months
Total locomotives owned	28	28	28	28	28
Total locomotive-hours	20,832	18,816	20,832	20,160	80,640
Locomotive-hours not available, segregated—					
Sanding	31	28	31	30	120
Brakeshoe maintenance, pantograph inspection, repairs, and lubrication	143	130	144	137	554
Mechanical and electrical repairs, inspection and testing	146	147	105	140	538
Total hours not available	320	305	280	307	1212
Per cent availability	98.47	98.38	98.66	98.48	98.5

when it is usually difficult to operate trains with any kind of power and especially so with steam equipment.

The snowfall in the vicinity of Butte and Anaconda for January and February was, respectively, 15.1 and 11.4 in. The average temperatures for the same periods were 14.7 and 17.5 deg. above zero, respectively. The minimum temperature for January was 24 deg., and for February, 15 deg. below, according to govermnent reports.

Locomotive Data

Excepting the passenger unit, the locomotives are operated two units coupled. Six doubles operate in the vicinity of Butte. The only attention that these locomotives receive is lubrication and brakeshoe adjustment. No facilities are provided for housing or inspecting.

When it is necessary to make inspection or repairs, the equipment is changed off with road crew locomotives and returned to Anaconda. Inspection is made in compliance with I. C. C. rulings.

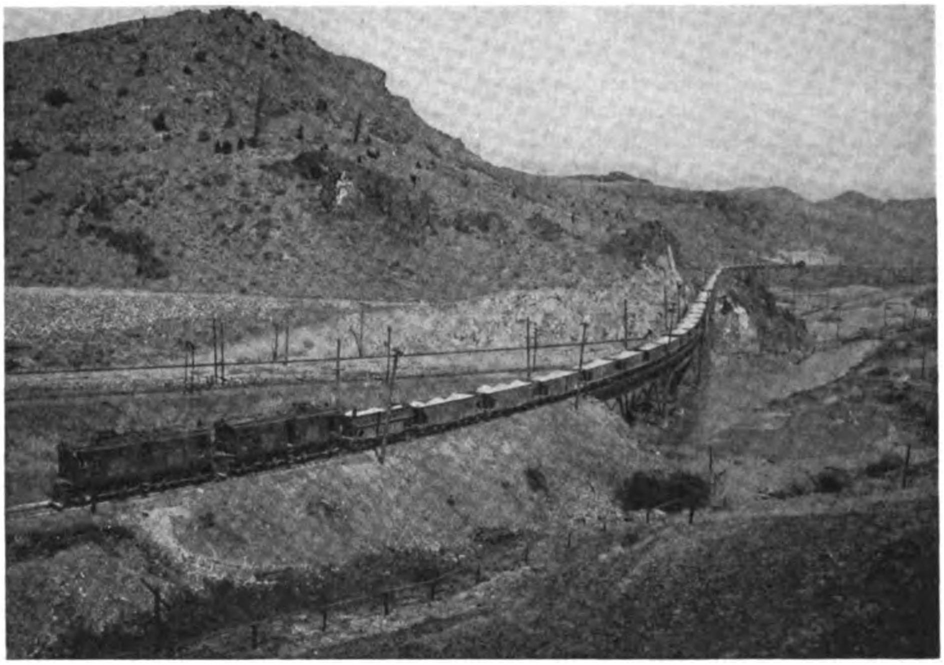


Fig. 1. Main-line Ore Train on the Butte, Anaconda and Pacific Railway, West Bound at Entrance of Silver Bow Canyon with 60 Loaded Cars Constituting a Trailing Load of 4200 Tons

Time in Service

It is interesting to note just how much time this equipment was actually used on the road by the operating department (See Table III). It is not possible to operate a railroad so that all locomotives are in service all of the time they are in serviceable condition. Statistics of steam locomotive operation show that serviceable locomotives actually operate about 30 per cent of the time.

TABLE III

	January	February	March	April
Total locomotive-hours worked	10,628	9,928	10,199	10,593
Average hours worked per day at Butte and Anaconda	12.24	12.66	11.75	12.61
Average hours worked per day at Anaconda	14.50	13.52	13.22	14.10
Number of locomotive units at Anaconda (including shop and passenger locomotives)	16	16	16	16

The principal data and dimensions of this equipment are given in Table IV.

TABLE IV

Length inside knuckles	37 ft. 4 in.
Length over cab	31 ft.
Height over cab	12 ft. 10 in.
Height with pantograph down	16 ft. 6 in.
Width over all	10 ft.
Total wheel base	26 ft.
Rigid wheel base	8 ft. 8 in.
Track gage	4 ft. 8.5 in.
Total weight	160,000 lb.
Weight per axle	40,000 lb.
Wheels steel tired (originally 46 in.)	47 in.
Journals	6 by 13 in.
Gear rims, forged, freight	87 teeth
Gear rims, forged, passenger	80 teeth
Pinions, forged, freight	18 teeth
Pinions, forged, passenger	25 teeth
Tractive effort at 30 per cent coefficient	48,000 lb.
Tractive effort, one-hour rating	30,000 lb.
Tractive effort, continuous rating	25,000 lb.
Current collector, roller pantograph, 5 in. dia., length (Mounted on roller bearings)	24 in.

Equipment Expense Low

It is obvious that the miles run per year in connection with the mining and smelting industry do not reflect the possibilities that are apparent with electric motive power. The B. A. & P. locomotives have operated approximately 9,000,000 miles in a period ending with the year 1928.

The average equipment expense per unit per mile is 6.21 cents. For the year 1927, the average cost of locomotive repairs on Class I railroads, including steam and electric locomotives, was about 27 cents, and the average tractive effort was approximately 43,000 lb. Therefore considering the continuous tractive effort of 25,000 lb. against the steam figures, the B. A. & P. equipment shows a decrease in maintenance per locomotive-mile of 60 per cent. Instead of locomotive repairs amounting to 10 to 15 per cent more than the cost of fuel we find that repairs amount to less than half of the cost for current.

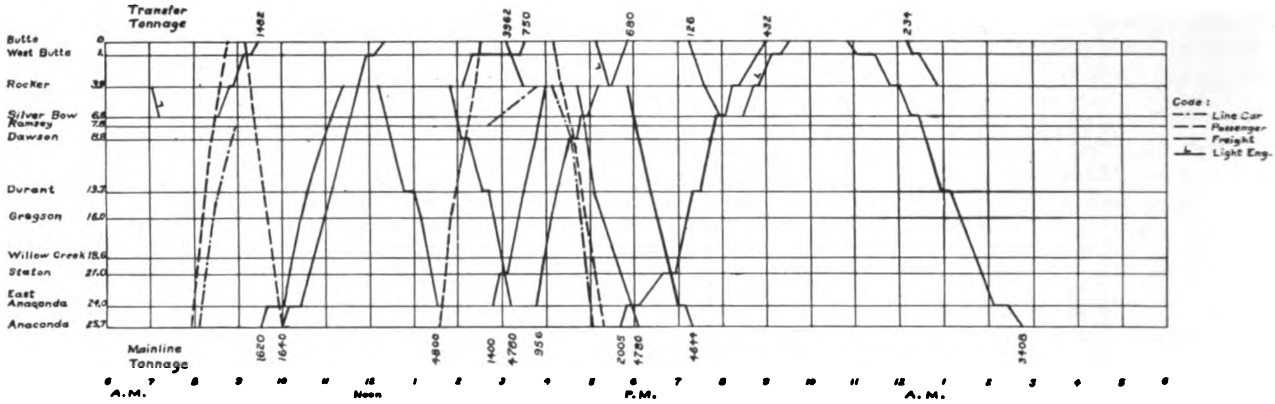


Fig. 2. Graphic Train Sheet of March 19, 1929 for Road-engine Movements on the B. A. & P. Ry.

Like many other electric locomotives, this equipment has not required a general overhauling. Repairs are made when necessary and may well be termed "running repairs." The locomotives are kept in first-class condition as may well be assumed from the high percentage of availability.

From the beginning of electric operation, an organization not exceeding three electricians has been maintained at Anaconda. These men handle all electrical inspecting, testing, and repairing in connection with the 28 locomotives together with the maintenance of coach heating (which is electric) and lighting, shop power, lights, etc.

Operating Conditions Severe

In order to visualize the locomotive movements in connection with the mining and smelting industry and to give emphasis to the dependability and high availability of electric operation, the following reverse movements of equipment per eight-hour shift were averaged over a period of one month:

Spotter locomotive	380
Night local (road crew)	168
Day local (road crew)	137

For the year 1928, these locomotives averaged 68.7 miles per day. For January and February of this year, the miles per day show an increase of 22.8 miles, or an average of 91.5 miles per day for all locomotives owned.

A graphic train sheet of the road engines is shown in Fig. 2. The complexity of switching operations makes impractical the preparation of a corresponding diagram of the switch engine movements.

Main-line service, as stated before, represents only slightly less than half of the engine-miles operated. This mileage is made with approximately 20 per cent of the motive power.

Shop Equipment

The B. A. & P. took over electric operation in a steam-equipped shop. Only three appliances have been added to assist in electrical maintenance: an inductive-type pinion heater; a tension device for banding armatures; and a portable slotting device. A six-ton manually-operated crane was replaced by one electrically operated, of the same capacity.

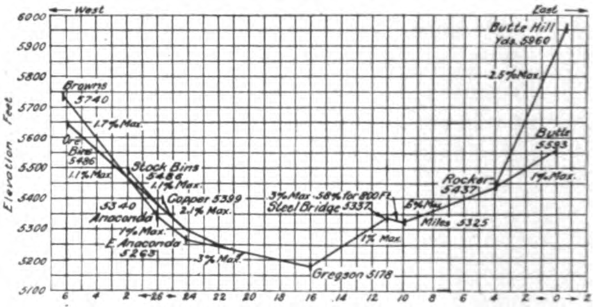


Fig. 3. Condensed Profile of the B. A. & P. Ry. Showing Elevation and Maximum Grades

Inspection and considerable maintenance work is performed out of doors, summer and winter. There are two reasons for this procedure. First, no inspection shed is provided. Shop facilities are limited to two short pit tracks each of which is 70 ft. in length. Second, frosting occurs when locomotives are placed in a warm shop during severe winter weather.

Conclusion

In July, 1925, *The Railway Electrical Engineer* correctly stated: "Electric locomotives on the Butte, Anaconda & Pacific are available for service 360 out of 365 days, 24 hours per day." Considering that these locomotives have seen heavy service for 16 years, it is gratifying to find that the availability has not become appreciably less. Based on an average of 98 per cent, it is evident that this equipment is available approximately 358 days out of 365.

Applying these figures so as to obtain the time out of service per day we find less than half an hour per locomotive per day. To be exact, each locomotive is out of service 0.467 hr. out of each 24.

Some of the advantages of electric operation have been slightly touched upon. Judging from our experience of sixteen years, electric locomotives possess features which make them superior for railroad operation, and the benefits apply equally to passenger and freight train operation.

With electric operation there is a saving of 15 to 25 per cent of the steam locomotive fuel which is consumed in standby losses. This saving, together with the high percentage of availability and the low cost of maintenance and operation, promises well indeed for electric operation. It is obvious that reliability is a function of availability. It is a requisite inherent to a high degree in the Butte, Anaconda & Pacific locomotives.

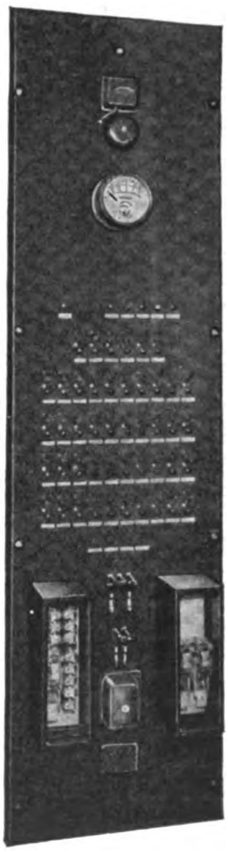
This equipment was so well engineered that the whole blends into a unit where no one quality emphasizes or sacrifices another so as to unfavorably affect the continuity of operation.

New Telemetering Equipment

A rectified-current type of telemetering, which is an improved design of remote metering equipment particularly adapted to transmitting volt and ampere readings of an alternating-current circuit in conjunction with synchronous selector supervisory equipment, is now available. This equipment, however, also provides an economical means of telemetering such readings over a pair of telephone wires.

When used with the synchronous selector supervisory system, this equipment does not require the installation of extra line wires. One transmitter and one receiver may be connected to any one of a larger number of substation circuits. The equipment is economical and simple to operate and maintain, since there are no moving parts except in the indicating or recording instruments at the dispatcher's station.

The synchronous selector system with which this new equipment is designed to operate provides for the centralized control and indication of various types of switching equipment located at outlying substations. With it, large or small groups of units can be coördinated, and thereby the application is broadened to include power systems of all sizes.



Dispatcher's Control Panel of a Synchronous Selector Supervisory Equipment

The new telemetering transmitter is simple and compact, consisting of the following equipment: a special transformer for each circuit to be indicated; a full-wave rectifier tube; a transformer to supply filament current to the tube; a line-wire compensating resistance; and protective equipment to prevent the possibility of high voltages in the event of opening of line wires or damage to equipment. The special transformers are of such design that the rectifier will deliver to the receiver approximately 25 milliamperes at full-load current or maximum voltage, as the case may be. The receiving instrument is a standard-type direct-current milliammeter adapted to panel mounting. When used in conjunction with a synchronous selector supervisory installation, it can be mounted on the dispatcher's control board.

Automatic Switching Equipment for 1500-volt Mercury-arc Rectifier

Complete A-c. Control—Essential Features of Rectifier Control—Establishment of Operating Conditions—Elements of Operation and Protection—Starting and Stopping—Details of Control—A-c. and D-c. Switching

By D. C. HOFFMANN
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General Electric Company

COMPLETELY automatic switching equipments for 600-volt and 1500-volt mercury-arc rectifiers have been installed and in operation in this country for a number of years. The majority of these equipments are for 600-volt rectifiers, and are essentially of a design that has been the subject of an article.(1) More recently, however, a new design of automatic switching equipment for 1500-volt rectifiers has been developed and several such equipments are now being placed into service. The design conforms in general with that of the lower-voltage equipment, but several features that make possible complete alternating-current control were incorporated.

No storage battery or other source of low-voltage direct-current control power for operating the various relays, contactors, and circuit breakers that constitute the automatic switching equipment is required in the new design. Only a small six-volt storage battery, trickle charged by a Tungar rectifier, both occupying less than a cubic foot of space, is necessary for the vacuum regulator.

Alternating current supplied from the a-c. incoming lines by a small control-power transformer has proved as efficient, reliable, and safe as the direct current supplied from a storage battery. It was developed for the automatic railway motor-generator and converter substations of comparatively low-voltage systems (600 volts or less) and has been applied practically ever since such substations were made automatic. For the smaller substations, it keeps the initial cost, installation cost, and the maintenance low, and in addition reduces the floor space required.

This article will deal almost entirely with the control scheme, the control devices, and the new features developed as a result of complete a-c. control. The arrangement of the devices on the switchboard of a typical 1500-volt equipment is shown in Fig. 1. The operating characteristics of a rectifier and the auxiliaries required for its operation have been previously dealt with in a recent article(1) applying more specifically to the rectifier itself. In order that the functions of the control may be more clearly understood, however, it may be well to enumerate the conditions that must exist for proper operation.

The valve action of the rectifier depends upon the maintenance of internal temperature and foreign gas pressure within certain limiting values. The temperature within the steel tank must be kept below a certain maximum value and also above a certain minimum value. The foreign gas pressure must be maintained below a fixed maximum value only, as the lower limit is the minimum pressure the evacuating equipment is capable of producing. If the temperature and foreign gas pressure are within proper limits, the only other requirement for operation is ignition, *i.e.*, an auxiliary or exciting arc must be struck in order to start the main arc.

Considering the above requirements of rectifiers, three important functions of the control become evident: (1) temperature control and protection against operating with the temperature either too high or too low, (2) foreign gas pressure control and protection against operating with the pressure too high, and (3) ignition and the maintaining of an exciting arc at all times while the rectifier is in operation.

In addition to these functions, the control must also perform all of the switching operations, which in the case of rectifier substations are comparatively few. The control must protect the rectifier and transformer from overloads, short-circuits, grounds, and other troubles common to all electrical machinery as well as trouble peculiar to rectifiers, such as arc-backs. Load-responsive starting and stopping of not only the first unit, but of each succeeding unit, and emergency starting of other units in case one or more leading units fail to start, are also functions of the control.

To assist in presenting these control functions and the manner in which they are performed by the various devices, an elementary or schematic diagram showing the control circuits of the rectifier has been made and is reproduced in Fig. 2. The various devices and their circuits are segregated according to their functions in the general control scheme. By referring to this diagram, it will be seen that the complete control for the rectifier may be divided into seven basic functions, as follows:

(1). Undervoltage Protection.
(2). Temperature Control and Protection.
(3). Foreign Gas Pressure Control and Protection.

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(1)"Automatic Control for Mercury-arc Rectifiers," by H. T. Seeley, GENERAL ELECTRIC REVIEW, October, 1928, p. 537.

(4). Load-responsive Starting and Stopping.
(5). Ignition and Protection.
(6). A-c. Switching Equipment Control.
(7). D-c. Switching Equipment Control.

Undervoltage Protection

In order to protect the auxiliary motors and the various a-c. contactors from damage due to insufficient control voltage, an a-c. undervoltage relay *No. 27* with an auxiliary contactor *No. 27X* is provided. There is no new or special feature in connection with this function, and the usual circuits and devices are used. It should be noted that the undervoltage relay *No. 27* is energized from control power transformer *No. 11-1*, and the auxiliary contactor *No. 27X* is energized from control power transformer *No. 11-2*. Since the two control power transformers are on different phases of the a-c. incoming line, the rectifier is prevented from operating if sufficient voltage is not available on all three phases.

Temperature Control Equipment

The inner steel tank of the rectifier is surrounded by a water jacket through which cooling water is constantly flowing. The flow of water is regulated to maintain the temperature of the tank within the proper limits by means of an automatic temperature-controlled water flow regulating valve. This valve is not shown in the schematic diagram as it is not electrically operated and does not take part in the sequence of operation. Tap water from city mains is used for cooling purposes if it is free from impurities. In isolated substations where suitable tap water is not available, a motor-driven water-circulating pump may be installed to maintain the proper pressure to insure a continuous flow of water. The source of water in such cases may be a well, or if well water is not available, a closed cooling system may be used in which the circulating water is cooled by air, using a blower fan and radiator.

Except in very warm climates, electric jacket heaters are provided to prevent the water from freezing when the rectifier is shut down. The jacket heaters are under the control of the thermostatic relay *No. 26* and its auxiliary contactor *No. 26R*. The relay, mounted on the rectifier, closes its contact *3* to energize the auxiliary contactor *No. 26R* when the temperature of the water approaches the lower operating limit. The auxiliary contactor *No. 26R* connects the insulating transformer for the jacket heaters to one of the control power buses. The jacket heaters are disconnected again by the opening of contact *3* of *No. 26* as soon as the temperature of the water is raised to a predetermined value.

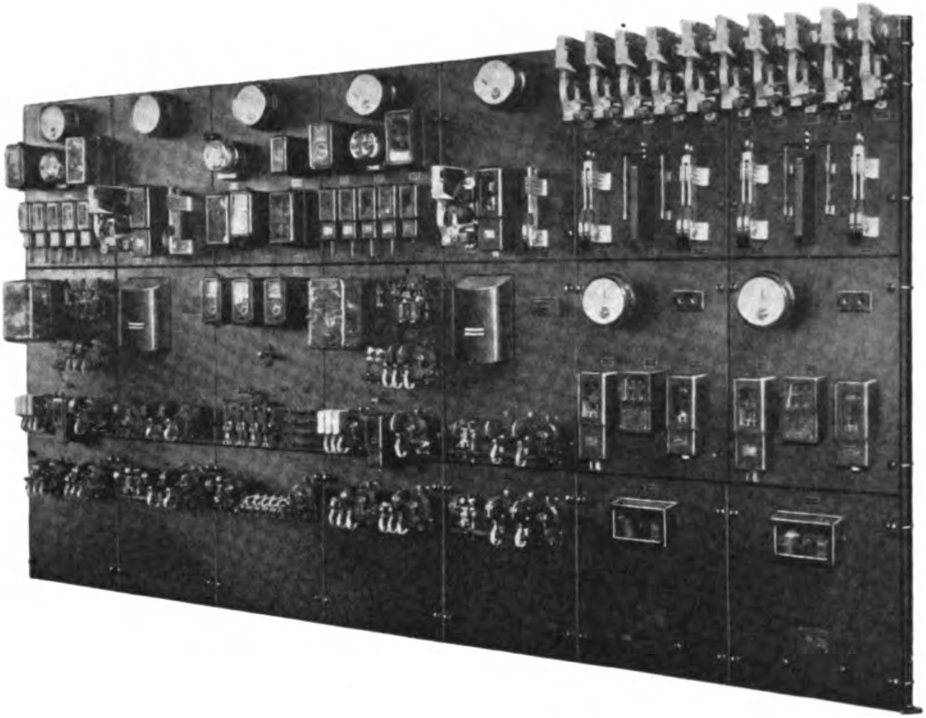


Fig. 1. Switchboard for the Control of a 1500-volt Mercury-arc Rectifier

The thermostatic relay *No. 26* is a new feature of the temperature control equipment. It is provided with three contacts insulated for 1500-volt d-c. service, and it replaces two similar relays formerly used for temperature protection and control. Contact *3*, as previously mentioned, controls the jacket heaters. Contacts *1* and *2* are in the coil circuit of master contactor *No. 4*. If the tank temperature becomes too high or too low, contact *1* or *2*, respectively, opens, the master contactor circuit and holds the rectifier out of service until the temperature of the tank is again within the proper limits.

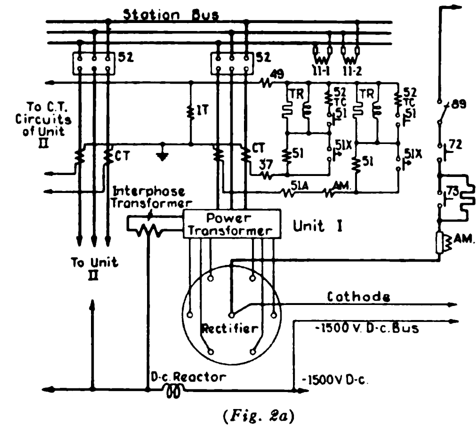
When the rectifier is carrying a light load or is shut down, the anodes are kept warm by means of individual electric heaters. As shown on the schematic diagram, there are six anode heaters connected in parallel and energized from the two secondary windings of an insulating transformer. In order to disconnect the anode heaters as soon as the load current is of sufficient magnitude to keep the anodes warm, an auxiliary contactor *No. 37X* is provided. This contactor is under the control of the a-c. undercurrent relay *No. 37*, and the circuits are so arranged that *No. 37X* picks up when *No. 37* drops out on undercurrent. As the operating coil of the relay *No. 37* is in the secondary circuit of the current transformers, the relay will function to keep the anode heaters connected at all times except when the load current is sufficient to maintain the anodes at the proper temperature.

Foreign Gas Pressure Control

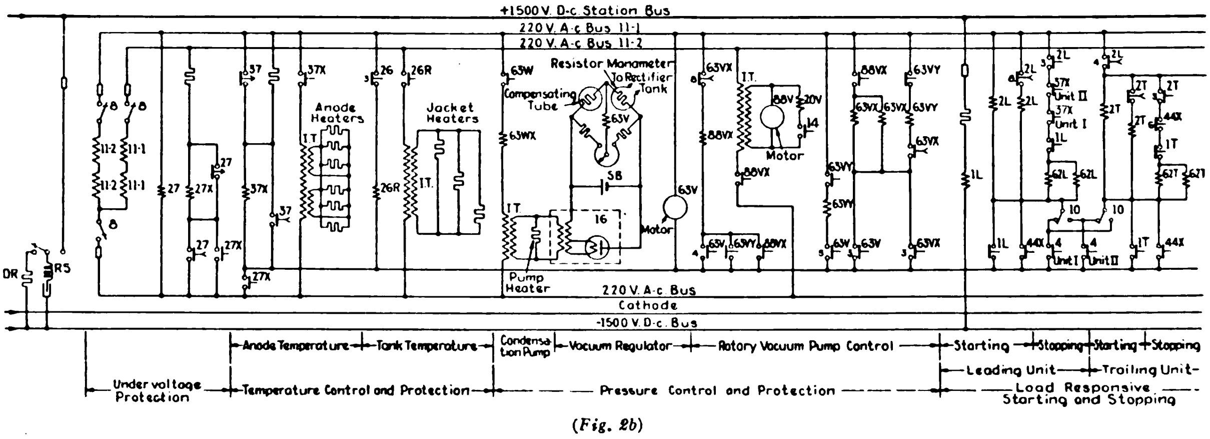
The evacuating equipment of a rectifier consists essentially of a motor-driven exhaust pump, a receiver, and a two-stage mercury condensation pump together with the necessary auxiliary devices and control relays. The two-stage mercury condensation pump is capable of evacuating the tank rapidly if the back pressure is well below atmospheric; and the purpose of the rotary exhaust pump is to reduce the back pressure. The rotary pump need operate only intermittently, as the condensation pump is capable of maintaining a sufficiently low pressure because of the reservoir interposed between the two pumps.

The condensation pump, as its name implies, depends upon the condensation of mercury vapor for its operation. The mercury is vaporized by an electric heater connected to the control power bus through an insulating transformer. In order to condense the mercury vapor thus formed, cooling water must flow at all times while the pump is in operation. In the primary circuit of the insulating transformer is the coil of a current-operated relay *No. 63WX*, and the contact of a water-flow relay *No. 63W*. Relay *No. 63WX*, acting as an undercurrent relay, prevents operation of the rectifier when the condensation pump heater circuit is open, and the water-flow relay *No. 63W* prevents operation of the pump and the rectifier when cooling water for the pump has stopped flowing. Although the battery-charging device *No. 16* is energized by the same transformer as the pump heater, the current taken by *No. 16* is not sufficient to hold in relay *No. 63WX*.

A feature of the pressure control equipment is the new design of vacuum regulator *No. 63V*, shown without cover in Fig. 3. The rotary exhaust pump motor *No. 88V* and its auxiliary contactor *No. 88VX* are under the control of the regulator and its auxiliary timing relay *No. 63VX* and auxiliary electrical reset relay *No. 63VY*. As shown on the elementary diagram, the circuit of the regulator is that of a Wheatstone bridge, consisting of a resistor manometer, a


Station Bus
52
52
49
11-1
11-2
TR
52 TC
51
TR
52 TC
51
69
To C.T. Circuits of Unit II
1T
CT
CT
37
51
51X
51
51X
72
51A
AM
73
LSR
Interphase Transformer
Power Transformer
Unit I
AM
To Unit II
Cathode
Rectifier
-1500 V. D-c. Bus
D-c Reactor
-1500 V D-c

(*Fig. 2a*)


+1500 V. D-c Station Bus
220 V. A-c Bus 11-1
220 V. A-c Bus 11-2
8
8
11-2
11-1
11-2
11-1
8
5
DR
RS
27
27X
27
27X
27
27X
27X
37
37X
37X
37
Anode Heaters
1T
26
26R
26R
Jacket Heaters
1T
63W
Resistor Manometer
To Rectifier Tank
Compensating Tube
63V
63WX
58
16
1T
Pump Heater
Motor
63V
63VX
1T
88VX
88V
20V
14
Motor
88VX
63VX
63VY
88VX
63VX
63VY
63VY
63VX
63VY
63W
63VY
63VX
63W
63V
63VX
1L
2L
2L
2L
2L
37X Unit II
37X Unit I
1L
62L
62L
10
10
44X
4
4
Unit I
Unit II
2T
2T
2T
2T
44X
1T
62T
62T
1T
44X
220 V. A-c Bus
Cathode
-1500 V. D-c Bus
Under voltage Protection
Anode Temperature
Tank Temperature
Temperature Control and Protection
Condensation Pump
Vacuum Regulator
Rotary Vacuum Pump Control
Pressure Control and Protection
Starting
Stopping
Starting
Stopping
Leading Unit
Trailing Unit
Load Responsive Starting and Stopping

(*Fig. 2b*)

Fig. 2. Schematic Diagram of Control Circuit

1L	Master element for leading unit (voltage relay)
1T	Master element for trailing unit (current relay)
2L	Time-delay starting relay for leading unit
2T	Time-delay starting relay for trailing unit
4	Master contactor
5	Manual stopping switch
8	Control power switch
10	Manually-operated unit sequence switch
10X	Manually-operated pull-button switch
11-1	Control power transformer
11-2	Control power transformer
14	Underspeed switch
16	Battery-charging device
20V	Vacuum valve
26	Rectifier-tank thermostat
26R	Auxiliary contactor for *26*
27	A-c. undervoltage relay
27X	Auxiliary contactor for *27*
28	Load shifting resistor thermostat
37	A-c. undercurrent relay
37X	Auxiliary contactor for *37*
44	Emergency starting relay
44X	Auxiliary contactor for *44*
49	A-c. thermal relay
51	A-c. overcurrent relay
51X	Auxiliary contactor for *51*
51A	A-c. overcurrent relay for load shifting resistor
51AX	Auxiliary contactor for *51A*
52	Oil circuit breaker
53	Ignition relay

compensating tube, two fixed resistors, and a potentiometer for adjustment. The coil of the regulator is connected across the bridge in place of the usual bridge galvanometer.

The resistor manometer consists of a wire resistance unit sealed in a glass bulb which is connected with the interior of the rectifier by means of a connecting tube. The compensating tube consists of a similar resistance unit in a glass tube entirely sealed up. The other two arms of the bridge consist of fixed resistors. The potentiometer is included for making adjustments. The bridge is energized by a small storage battery *SB*, trickle charged by a Tungar rectifier *No. 16* operating from the same insulating transformer that supplies power to the condensation pump heater.

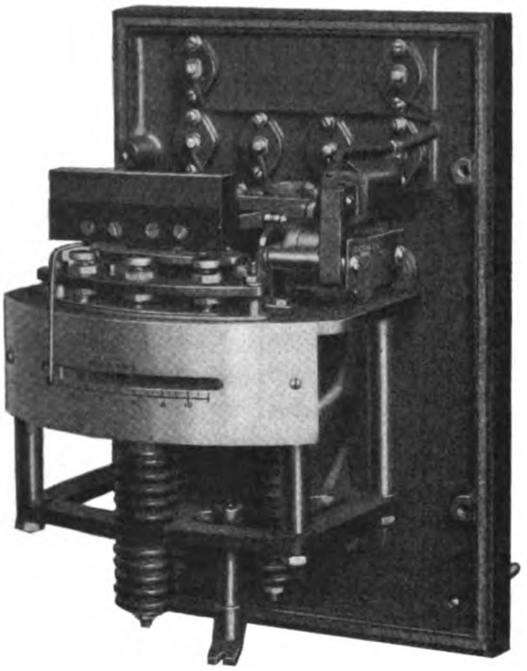
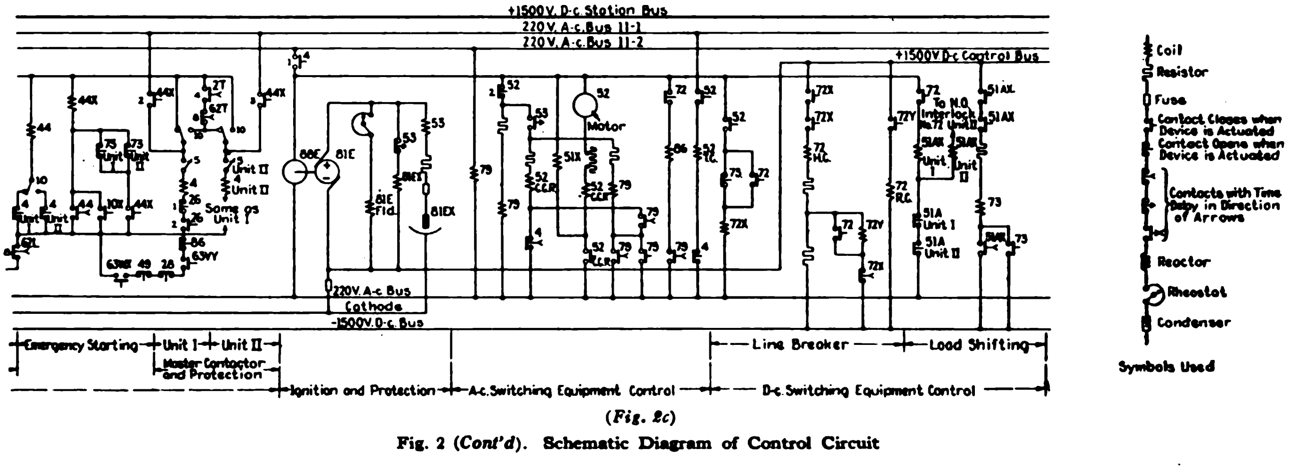


Fig. 3. New Design of Vacuum Regulator Used in Rectifier Pressure Control

As the resistor manometer is connected to the rectifier, the pressure in the manometer bulb is equal to the pressure in the tank. The rate of dissipation of the heat produced by the current flowing through the resistance unit depends upon the gaseous pressure in the bulb and the ambient temperature of the bulb. The rate of dissipation of the heat produced by a similar resistance bulb depends only upon the ambient temperature. Any unbalancing of the bridge is therefore due to a change of resistance of the manometer bulb and is proportional to the change in the foreign gaseous pressure in the rectifier tank.

The regulator *No. 63V* is essentially a contact-making microammeter. The contacts *5*, *4*, and *3* are closed momentarily and in the order named as the pressure in the tank decreases, and in the reverse order as the foreign gas pressure increases. A small synchronous motor, by means of a cam mechanism, allows the regulator to operate its contacts only at regular intervals of time, which are usually of thirty seconds duration.

The regulator *No. 63V* operates the rotary pump motor auxiliary contactor *No. 88VX* directly or through its auxiliary relays *No. 63VX* and *No. 63VY* to start or stop the pump. The contact *5* is closed at high pressure, the contact *4* at an intermediate pressure, and the contact *3* at low pressure. The control circuits are so arranged that as the pressure increases, the intermediate contact *4* causes the rotary pump to start, but the rectifier is not taken out of service until the high-pressure contact *5* is closed. On the other hand, the rectifier is not put back into service again until the low-pressure contact *3* is closed, as the intermediate contact *4* has no effect


+1500 V. D-c Station Bus
220 V. A-c Bus 11-1
220 V. A-c Bus 11-2
+1500 V D-c Control Bus
220 V. A-c Bus
Cathode
-1500 V. D-c Bus
Motor
Emergency Starting
Unit I
Unit II
Master Contactor and Protection
Ignition and Protection
A-c. Switching Equipment Control
Line Breaker
Load Shifting
D-c. Switching Equipment Control
Coil
Resistor
Fuse
Contact Closes when Device is Actuated
Contact Opens when Device is Actuated
Contacts with Time Delay in Direction of Arrows
Reactor
Rheostat
Condenser
Symbols Used

(*Fig. 2c*)

Fig. 2 (*Cont'd*). Schematic Diagram of Control Circuit

62L...Time-delay stopping relay for leading unit
62T...Time-delay stopping relay for trailing unit
63V..Vacuum regulator
63VX.Auxiliary timing relay for *63V*
63VY.Auxiliary relay for *63V*
63W .Water-flow relay
63WX.Auxiliary relay for *63W*
72....D-c. high-speed circuit breaker
72X..Auxiliary contactor for *72*
72Y..Auxiliary relay for *72*
73....Load-shifting-resistor shunting contactor

79....A-c. reclosing relay
81E...Arc-striking generator
81EX.Arc-striking anode
86....Locking-out relay
88E...Auxiliary motor for arc-striking set
88V...Auxiliary motor for vacuum pump
88VX.Auxiliary contactor for *88V*
89....D-c. line switch

AM..Ammeter
CCR..Control contactor

CT...Current transformer
DR...Discharge resistor
FLD..Generator field (*81E*)
HC...Holding coil
IT....Insulating transformer
LSR..Load-shifting resistor
RC...Reset coil
RS...Resonant shunt
SB....Storage battery
TC ..Trip coil
TR...Tripping reactor

when pressure decreases unless the high-pressure contact *5* has failed to start the pump.

Even though the rectifier is allowed to start as soon as contact *3* closes, the pump is not shut down until after a time delay. The timing relay *No. 63VX* interposes this time delay between the closing of contact *3* of *No. 63V* and the shutting down of the pump. The purpose of the time delay is to enable the pump to thoroughly exhaust the receiver. This scheme allows the rectifier to remain in service as long as possible; for the pump need run only a short time to restore proper pressure, and the rectifier is not taken out of service unnecessarily.

The solenoid-operated vacuum valve *No. 20V* is placed in the line between the rotary pump and the reservoir in order to prevent leakage back through the pump when the pump is not in operation. The solenoid is energized by the underspeed switch *No. 14* (on the shaft of the pump motor) when the pump is up to approximately normal speed. When the speed of the pump decreases, in the operation of shutting down the pump, the valve is automatically closed.

It should be noted in connection with the temperature and pressure control scheme that the rectifier is not locked out under any condition of temperature or pressure. It is merely taken out of service if the limits of temperature and pressure are reached, and held out of service until proper conditions are restored. It is considered needless to lock-out a rectifier because of improper temperature and pressure conditions, for such conditions will usually right themselves in a short time.

Load-responsive Starting and Stopping

The starting indication for the leading unit is gven by a d-c. undervoltage relay *No. 1L* connected through a fuse directly across the 1500-volt station bus. In order to provide an adjustable time delay in starting and to prevent starting the unit unnecessarily from fluctuations of the bus voltage, a time-delay starting relay *No. 2L* is provided. The normally-closed contact of the undervoltage relay *No. 1L* energizes the time relay *No. 2L* when the d-c. bus voltage falls to an adjustable predetermined value. If undervoltage continues for the length of time for which *No. 2L* is set, the contact *4* of *No. 2L* closes and completes a circuit for the master contactor *No. 4* of either *Unit I* or *Unit II*, depending upon the position of the unit sequence switch *No. 10*. With *No. 10* in the position as shown on the diagram, *Unit I* is the leading unit. The circuit of the master contactor *No. 4* includes the contacts of all the protective devices, and the unit cannot start unless all of these contacts are closed, indicating normal operating conditions.

The indication to shut down the leading unit is given by undercurrent relay *No. 37*. When the load current has decreased to a predetermined value, this relay closes its normally-closed contact to energize the auxiliary contactor *No. 37X* as described under the heading "Temperature Control." The undervoltage relay *No. 1L* indicates normal bus voltage by closing its normally-open contact. The time-delay stopping relay *No. 62L* is energized and begins to time for shut down. If undercurrent conditions exist for the length of time for which *No. 62L* is set, the normally-closed contact *8* of *No. 62L* opens the coil circuit of master contactor *No. 4* to shut down the leading unit.

The purpose of the emergency starting relay *No. 44* is to start the trailing unit if for any reason the leading unit fails to start. It is energized when contact *4* of time-delay starting relay *No. 2L* closes and if the master contactor *No. 4* of the leading unit fails to pick up. After a time delay, the contact of *No. 44* closes and the auxiliary contactor *No. 44X* is energized. The contacts *2* and *3* of *No. 44X* complete the coil circuit of master contactor *No. 4* of *Unit I* and *Unit II*, respectively, directly to the control power bus, thereby starting the trailing unit. It should be noted that if the leading unit starts while the trailing unit is in serivce, the auxiliary contactor, *No. 44X* is de-energized by the opening of the normally-closed interlock on the load-shifting-resistor shunting contactor *No. 73* of the leading unit. The contacts *2* and *3* of *No. 44X* open, and if both units are not required, the trailing unit is shut down, leaving the leading unit in service, as was originally intended. The leading unit is not shut down, however, until the trailing unit is connected to the bus, thus preventing an interruption of service.

When the load on the leading unit reaches a certain predetermined value, the starting indication for the trailing unit is given by an a-c. overcurrent relay, *No. 1T*, the coil of which is in the current transformer circuit. Since the ratio of a-c. current to d-c. current is constant, an a-c. overcurrent relay may be used to initiate the starting sequence of the trailing unit. The connections are such that the secondary current of the transformers of both units returns through the coil of relay *No. 1T*. Assuming that the leading unit is in operation, and that the load increases to the predetermined value at which it is desired to start the trailing unit, the normally-open contact of *No. 1T* closes to energize the time-delay starting relay *No. 2T*. If overload of the leading unit persists for the length of time for which *No. 2T* is set, contact *4* of *No. 2T* closes and energizes the master contactor *No. 4* of the trailing unit through the unit sequence switch *No. 10*.

As soon as the load on the station is reduced to a certain value, the trailing unit is no longer required; and relay *No. 1T* closes its normally-closed contact to energize the time-delay stopping relay *No. 62T*. If the underload conditions persist for the length of time for which *No. 62T* is set, contact *8* of *No. 62T* opens to de-energize the master contactor *No. 4* of the trailing unit.

In order that either unit may be made the leading unit, a unit sequence switch *No. 10* is provided. This device is a five-pole double-throw lever switch of the voltage regulator type. When it is in the position shown in the diagram, *Unit I* is the leading and *Unit II* is trailing. By throwing *No. 10* to the other position, the order of the units is reversed. The purpose of the pull-button switch *No. 10X* is to provide a means of making this change in position of *No. 10* without interrupting service in case the change is made while one or both rectifiers are in service.

Ignition

In order to establish the main arc between the cathode and anodes, an auxiliary or exciting arc is necessary. The exciting arc is struck by means of a solenoid-operated auxiliary anode *No. 81EX*. A low-voltage direct current is supplied for this purpose by a small motor-generator set which starts as soon as the master contactor *No. 4* is closed. The auxiliary anode is held out of the mercury pool of the cathode by a spring. When the coil of *No. 81EX* is energized by the generator *No. 81E*, the spring is compressed and the auxiliary anode is dipped into the mercury pool of the cathode. The resultant current flowing through the ignition relay *No. 53* causes it to open its normally-closed contact and de-energize the solenoid of *No. 81EX*. When the auxiliary anode is withdrawn from the mercury by the action of the spring, the exciting arc is struck. The relay *No. 53* remains energized as long as the exciting arc is not extinguished. In case the exciting arc is not established, the starting sequence of the rectifier cannot proceed, because of the normally-open contact of *No. 53*. The exciting arc is maintained at all times when the rectifier is in service.

A-c. Switching Equipment Control

As soon as the exciting arc is struck, as indicated by the operation of the ignition relay *No. 53*, the oil circuit breaker *No. 52* is closed. This initial closing circuit is made by a normally-closed time-delay opening interlock of master contactor *No. 4*. The purpose of this arrangement is to provide a means for closing the oil circuit breaker immediately after the exciting arc is struck and without waiting for the first closing operation of the a-c. reclosing relay *No. 79* to occur. This feature eliminates the time delay of the a-c. reclosing relay and thereby greatly decreases the time required to get the rectifier into service.

It should be noted, however, that all subsequent reclosures of *No. 52* are under the control of the reclosing relay *No. 79*, because the time-delay interlock on master contactor *No. 4* remains open until *No. 4* is de-energized on shut-down. A standard reclosing relay which will allow the oil circuit breaker *No. 52* to reclose three times in succession is used for *No. 79*. If the circuit breaker fails to remain closed after the third attempt, the rectifier is locked out by the locking-out relay *No. 86*. The coil of *No. 86* is energized by a contact of *No. 79* that closes soon after the third reclosing operation has been completed. If the line breaker *No. 72* is closed at this time, however, which means that the circuit breaker *No. 52* remained closed, the lock-out circuit of *No. 86* is not effective because it is opened by a normally-closed interlock of *No. 72*.

During normal shut-down, the circuit breaker *No. 52* is tripped by a normally-closed interlock of *No. 4*. In case of a short-circuit exceeding two or three times normal current, *No. 52* is tripped by one or both of the instantaneous a-c. overcurrent relays *No. 51*. The breaker will then be reclosed as many as three times by *No. 79* before the rectifier is locked out.

As the overcurrent relays *No. 51* are instantaneous in operating, it is necessary to provide an auxiliary contactor *No. 51X* to prevent tripping the oil circuit breaker on the heavy transient current which may flow at the instant the transformer is energized. To accomplish this purpose, the auxiliary contactor *No. 51X* is energized at the same time as the motor of the breaker-operating mechanism. The contacts of *No. 51X* then short-circuit the coils of the overcurrent relays *No. 51*. When the oil circuit breaker closes, the motor and *No. 51X* are deënergized slightly after the main contacts of the breaker have closed. This time delay is of sufficient duration to allow the transient current of the transformer to disappear. As *No. 51X* drops out, the coils of the overcurrent relays are inserted in the circuit and normal protection is again effective in a very short time after the breaker contacts have closed.

D-c. Switching Equipment Control

The d-c. switching equipment consists of a high-speed circuit breaker *No. 72* and a load-shifting-resistor shunting contactor *No. 73*. A-c. operated contactors designed to handle the 1500-volt d-c. coil circuits of *No. 72* and *No. 73* are used as auxiliary contactors. The application of these contactors to control the 1500-volt d-c. switching devices is one of the features of the control scheme that permitted the elimination of a storage battery as a source of control power. The auxiliary contactor *No. 72X* closes as soon as the breaker *No. 52* is closed and energizes the holding coil of the high-speed circuit breaker *No. 72*. The coil of the closing relay *No. 72Y* is connected in series with the holding coil and is energized at the same time. The high-speed circuit breaker closes in the usual manner, the reset coil being energized by the auxiliary relay *No. 72Y*. A normally-open interlock of *No. 72* short circuits the coil of the closing relay *No. 72Y* when *No. 72* closes, causing *No. 72Y* to de-energize the reset coil of *No. 72*. A time-delay circuit-opening interlock of *No. 72X* opens the coil circuit of *No. 72Y*, leaving the holding coil of *No. 72* across the bus, in series with two resistors.

The connections of the high-speed circuit breaker *No. 72* are such that it will open instantly on reverse current and disconnect the rectifier from the d-c. bus. The instantaneous overcurrent relays *No. 51* trip the oil circuit breaker *No. 52* to remove the a-c. voltage; and *No. 72* opens to prevent the bus from feeding power back into the rectifier.

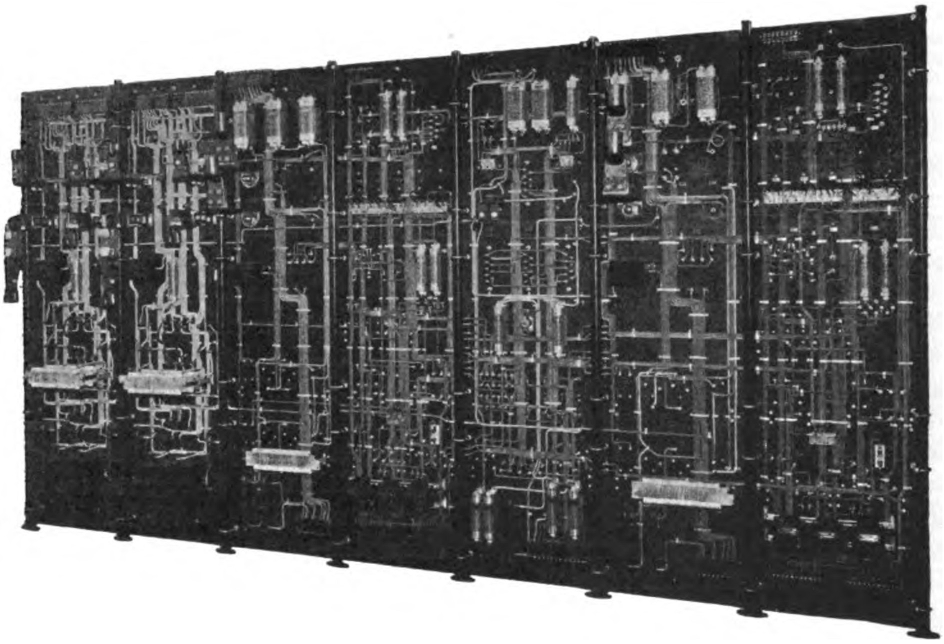


Fig. 4. Rear View of a Switchboard for 1500-volt Mercury-arc Rectifier Control

As the ratio of a-c. current to d-c. current is practically constant, an a-c. overcurrent relay *No. 51A* is used to insert the load-shifting resistor when the rectifier becomes overloaded. The opening and closing of the load-shifting-resistor shunting contactor *No. 73* is controlled by the overcurrent relay *No. 51A* and the a-c. operated 1500-volt auxiliary contactor *No. 51AX*. This substitution of a simple a-c. overcurrent relay and auxiliary contactor with time-delay interlock is practicable because the reverse-current protection feature incorporated in the high-speed circuit breaker *No. 72* is sufficiently sensitive for rectifiers. In order to obtain the required sensitivity of the reverse-current relay for the proper protection of synchronous motor-generator sets and converters, it is necessary to use some form of relay shunt, and in such cases, the d-c. overcurrent relay is operated from the same shunt. The unusual accessibility of the connections on the back of the board is the result of the elimination of the shunt on rectifier equipments, as shown in Fig. 4.

When the load on the rectifiers reaches the value for which relays *No. 51A* are set to operate, the normally-closed contact of *No. 51A* of either *Unit I* or *Unit II*, or both, opens the coil circuit of *No. 51AX* of both units. The opening of *No. 51AX* deënergizes *No. 73* which inserts the load-shifting resistors in the rectifier circuits. When the load drops to a predetermined value, the contact of *No. 51A* is closed and *No. 51AX* picks up. After a time delay determined by the time delay closing interlock of *No. 51AX*, the load-shifting resistors are shunted again by *No. 73*.

General

In order to trap the high-frequency ripples present in the d-c. circuit of the rectifier to prevent them from causing telephone interference, resonant shunts consisting of reactors and condensers are connected across the station bus as shown in the schematic diagram. These shunts may consist of several sections, each tuned to a different harmonic frequency of the a-c. current. A discharge resistor is provided to allow the condensers of the shunts to be discharged when they are taken out of service.

It should be noted that the steel tank of the rectifier is exposed to the mercury arc, and is approximately at the same potential as the cathode; *i.e.*, 1500 volts above ground potential. All devices and circuits connected to the tank will likewise be at a potential of 1500 volts above ground. The purpose of the insulating transformers used with the anode heaters, jacket heaters, condensation pump, battery charging device, and vacuum pump motor is to isolate these devices from the control circuits. Since all circuits connected with the ignition generator *No. 81E*, which is a low-voltage machine in itself, are at positive rectifier potential, the generator is not used as a source of d-c. control power.

750-kw. High-voltage Rectifier

By I. J. KAAR
Radio Engineering Department, General Electric Company

THE economic production of direct current at high voltage has long been a subject of vital interest to the electrical engineer in the power transmission field and in various specialized engineering fields. Direct-current power transmission at high voltage has a great many advantages over the existing alternating-current systems; but practical consideration of a system of this kind has been impossible because of the lack of ways and means of generating any reasonable amount of power at high voltage. There are many other serious objections to a system of this kind, but the problem of the initial generation of high voltages, economically, now seems to be well on the road to solution.

An impetus has been given to the solution of the problem of high-voltage direct-current production by the demands of the radio transmitter art. As the required power from radio transmitters has steadily increased during the last decade, it has been necessary to steadily increase the capacity and the voltage of the direct-current sources used to drive these transmitters. With the exception of a few installations, the high-vacuum Kenotron rectifier has been used to supply the necessary high-voltage direct current. The high-vacuum Kenotron, however, has certain inherent characteristics which introduce difficulties into the design of rectifiers having high efficiency and good regulation, and consequently effort was directed toward the production of a thermionic tube in which the space-charge potential drop would be reduced.

Tubes having these desired characteristics have been produced commercially and have been applied to a rectifier recently constructed for radio transmitter service. (Figs. 1 and 2).

The rectifier is designed to deliver 50 amp. at 15,000 volts, and the equipment thereby represents probably the largest high-voltage rectifier yet produced commercially.

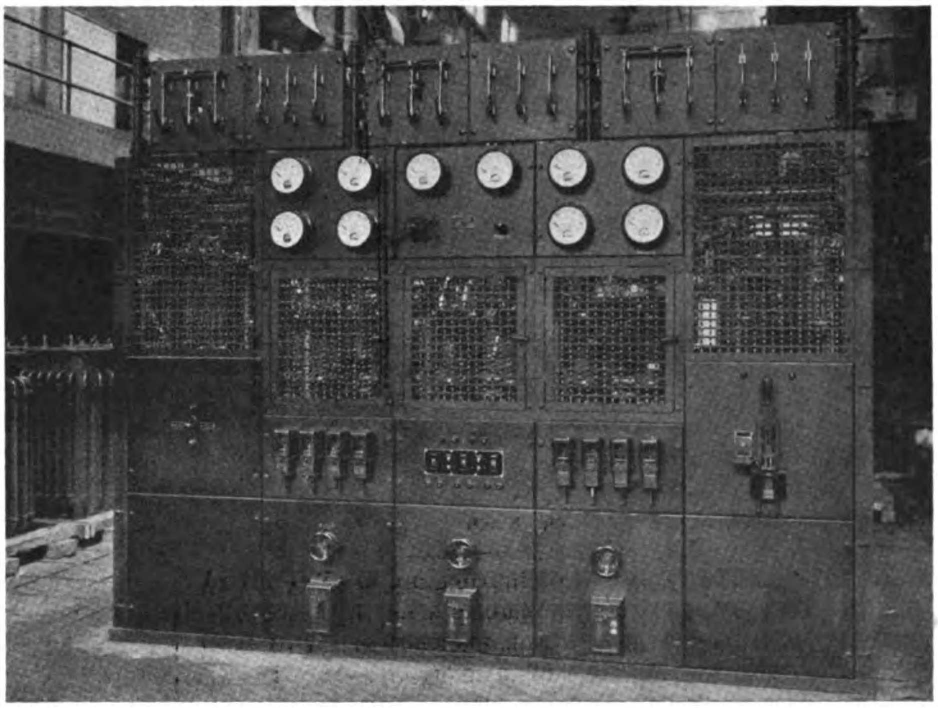


Fig. 1. Control Panel at the Front of the 750-kw. 15,000-volt Mercury-vapor Rectifier

The hot-cathode mercury-vapor rectifier tubes used represent one of the recent noteworthy contributions to the rectifier art. These tubes have been under development for a considerable period of time(1) and not until the past year have they been applied to commercial service. Probably the most outstanding feature of these tubes is their remarkable efficiency. The particular type employed in this rectifier is shown in Figs. 3 and 4 and is capable of passing 20 amp. with a potential drop of only 18 volts. The potential drop in the tube is practically independent of the current, and for this reason particular care must be exercised when operating such tubes in parallel to make certain that each tube carries its share of the load.

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(1) "Gas-filled Thermionic Tubes," by Dr. A. W. Hull, *A.I.E.E. Transactions*, Vol. 47, July, 1928, p. 752.

A total of 18 of these tubes is used in the rectifier, arranged in three independent channels of 6 tubes each (Fig. 3). Each channel is provided with a separate surge reactor which serves the double purpose of keeping the load equalized among the three channels and assisting in the reduction of the 300-cycle ripple inherent in this type of circuit. (The line frequency is 50 cycles.) A common high-voltage condenser bank completes the smoothing network, and results in a direct-current output having a ripple component in the order of 0.05 per cent.

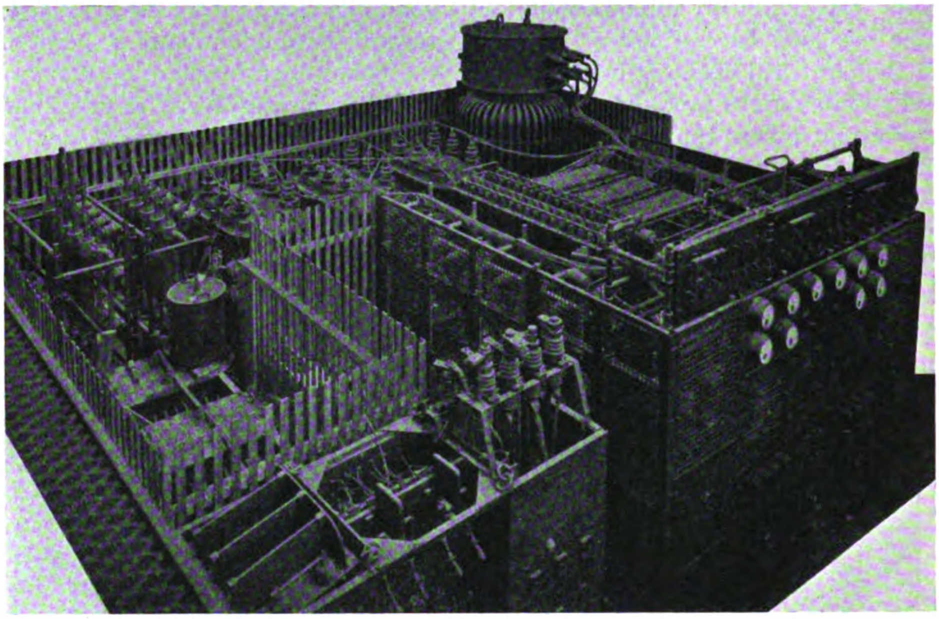

Fig. 2. View of the Rectifier from Above. The control panel is at the front right, the regulator in the background together with the transformers and water-cooled test dissipator, and the direct-current reactors at the left near corner within the enclosure. The equipment in the immediate foreground is a testing table and not a part of the rectifier, nor is the water-cooled test dissipator

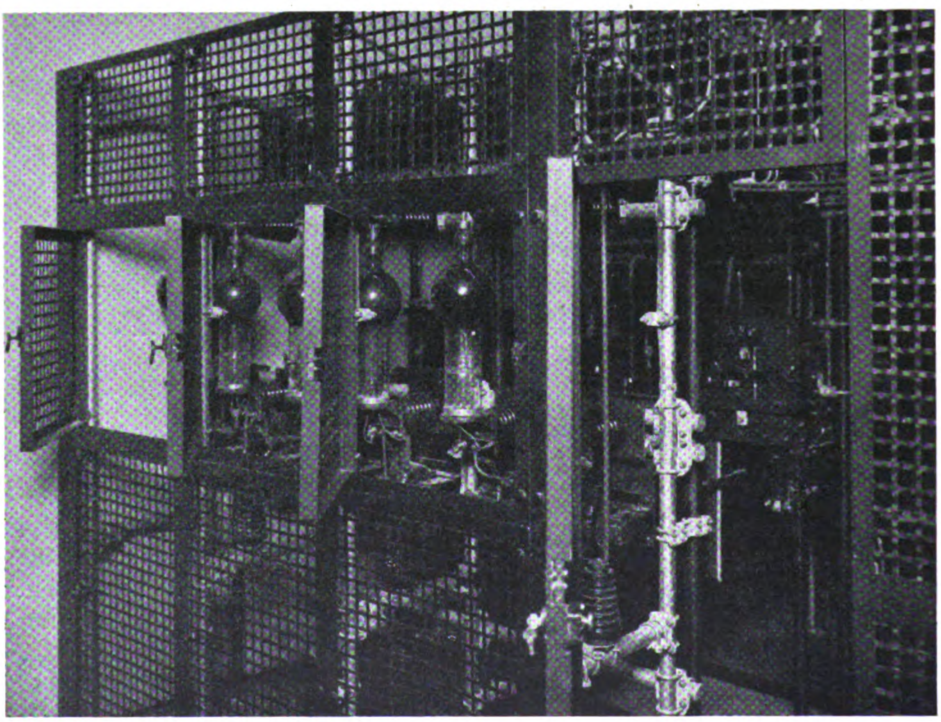

Fig. 3. The Left Bank of Six Half-wave Rectifier Tubes. This with two other like banks comprise the rectifying tube equipment

The circuit used for each of the three channels is known as the "three-phase full-wave connection" and is shown schematically in Fig. 5. This circuit has a number of advantages over the well-known "double Y" and "triple T" circuits, commonly associated with high-voltage rectifier practice. Chief among these advantages is the fact that no special design is necessary for the plate transformers. It will be observed from Fig. 5 that rectification occurs during each half cycle of each phase and consequently there is no direct-current component in the windings. Since rectification takes place over both halves of the cycle, the transformer windings are utilized to practically the same extent as they would be under alternating-current load conditions. This is in contrast to well-known circuits wherein rectification takes place only during each half cycle and where special precautions must be taken to neutralize the magnetizing component in the cores. The theoretical input power-factor of this circuit is 0.955 lagging. The power-factor of the transformer secondary also has this same value, indicating that the windings are used very efficiently. The circuit used has long been known to the art but has not been used extensively until the advent of the mercury-vapor tube because of the regulation which would result if the conventional high-vacuum rectifier tubes were used. It should be observed that there are two tubes effectively in series with the load in this connection and that the resulting space-charge drop would be prohibitive if high-vacuum tubes are used. A total voltage drop of approximately 2400 volts between full load and no load would have to be tolerated in the best design of high-vacuum tube rectifiers whereas the total drop is only 1250 volts under the same conditions for this rectifier. This voltage drop includes the regulation of the transformers, regulators, tubes, reactors, etc.

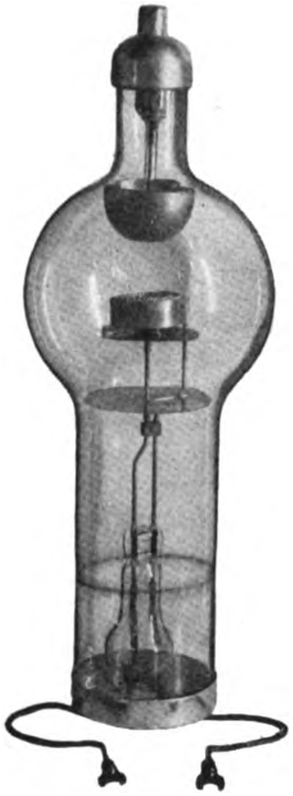

Fig. 4. One of the Eighteen Two-element Half-wave Rectifying Tubes which Form Part of the Equipment

Any single channel can be used alone, or any two channels or all three may be used at once. Switching is accomplished by the disconnecting switches shown at the top of the panel in Fig. 1. These switches perform four functions as follows:

(1). Connect the supply line to the proper channel.
(2). Connect the proper value of starting resistance in the line.
(3). Connect the output bus to the proper channel.
(4). Render the protective devices inoperative on any unused channel.

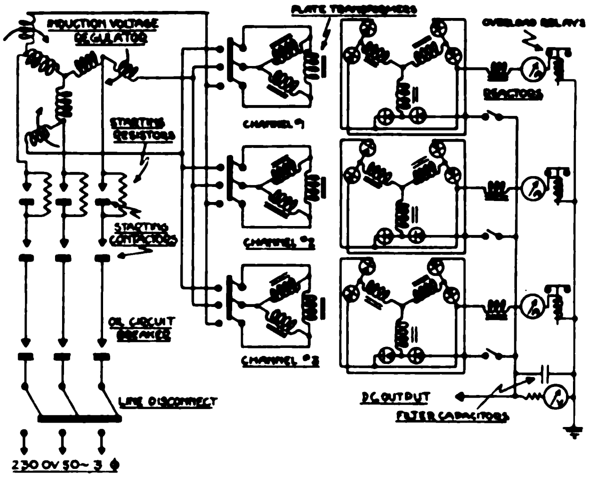

Fig. 5. Circuit Diagram of the Rectifier. Each channel employs the three-phase full-wave connection

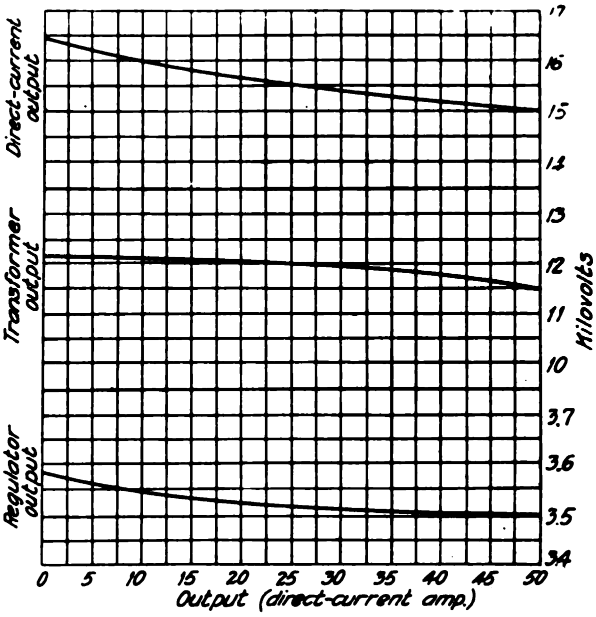

Fig. 6. Performance Curves of the Rectifier

Starting is accomplished in two steps in order to reduce switching transients. Two oil contactors are connected in series in the main supply line. The first of these closes the circuit to the transformer through a value of resistance which limits the current to about half normal value. After an adjustable time delay the second contactor short-circuits the resistor. In case of overload, both contactors open simultaneously.

The entire installation is controlled from the front of the panel (Fig. 1). Indicator lamps are provided for visual indication of circuit conditions.

The output voltage is adjustable between 4000 and 15,000 volts by means of an induction voltage regulator in the main feeder. This regulator is shown in the background of Fig. 2 and is controlled by push buttons on the control panel.

Meters are provided on the panel for all major circuits and for the output of each channel.

Particular attention was given to the protection of the operating personnel. The panel is of dead-front construction. The access doors are interlocked and trip the main oil switches when opened.

Short-circuit and overload protection is afforded by a system of overload relays operating in conjunction with the main-line oil contactors. One of these relays operates instantly in the case of sudden heavy overload while another relay operates if a sustained less severe overload occurs. Both of these relays will effectively remove all power from the rectifier.

It is necessary when using the mercury-vapor tube to have the filament at operating temperature before plate voltage is applied, otherwise back bombardment would soon destroy the cathode. Protection against this danger is provided by a time-delay relay which prevents plate voltage from being applied until proper filament operating temperature is attained. The tubes are further protected by sensitive undervoltage relays which operate the main contactors should the filament fall below a safe value at any time.

The operating characteristics obtained on test may be summarized by the following table: Performance curves are given by Fig. 6.

Input power: 2300 volts, 50 cycles, 3-phase delta.
Output power: 4000-15,000 volts d-c.; 0-50 amp. d-c.
Output ripple: Approximately 0.05 per cent.
Conversion efficiency at full load: 96 per cent.
Input power-factor: 92 per cent lagging.
Overall regulation from no load to full load: Approximately 8.6 per cent.

Welded Buildings Increase 50 Per Cent in One Year

The number of buildings erected by the use of electric arc welding has increased 50 per cent during the space of one year, according to lists prepared by Frank P. McKibben, nationally known authority on the subject. In the list published in the July, 1928, issue of the Review, the number of welded buildings was 43, and the total to date is 65 or more. If to this total are added bridges and ships, the total is 95 or more as against 63 for a year ago, each item having increased by the same percentage.

Three interesting developments are pointed out by Mr. McKibben as occurring during this period. He says:

"The most notable advance has been in the increased height and size of buildings in which electric arc welding has been used. As evidence of this, one need point to the outstanding examples of the steam power plant of the hotels Chalfont and Haddon Hall in Atlantic City (N. J.) and the new Hotel Homestead, Hot Springs (Va.) with heights of 150 and 180 ft. respectively.

"A second interesting development is the comparative ease by which existing steel bridges are strengthened by welding new steel to corroded or overstressed members, a process applied not only to highway structures but to steam railroad bridges as well. Indeed, welding could ask for no better endorsement than this adoption by some of the leading railway systems of the world.

"Of no less interest than the two previously mentioned phases of welding progress is the changed attitude toward welding exhibited by many officials of municipal building departments who are permitted welding and at the same time are modifying their building codes to authorize welding of steel building frames. Among the most interesting developments in building codes has been the publication of a uniform building code by the Pacific Coast Building Officials Conference, Section 2710 of which covers welding, and its adoption by over 40 towns and cities, thus legalizing the construction of welded buildings. The Pennsylvania Legislature has passed a law permitting building departments of cities of the first class to adopt rules and regulations to cover welding, and the American Welding Society has also formulated a code applicable to welding of steel building frames."

According to Mr. McKibben, such legislation is needed throughout the entire country. "This method of construction," he says, "has been successfully applied to many buildings in this country, varying in height from one to eleven stories, the one containing the greatest amount of steel being a factory building constructed by the General Electric Company in Philadelphia. So many successful applications have been made that the process has been removed from the realm of experimentation and its usefulness is established as a satisfactory tool for constructive effort, not only in structural steel work but also in many other fields."

Electrification of a Large Gold Mine

By J. F. WIGGERT
Electrical Engineer, Lead, South Dakota

The author has written a fascinatingly interesting story of the development of the famous Homestake Mines at Lead, South Dakota. His narrative is rich in the history of the application of electricity to mining operations.
—EDITOR

BEFORE describing the part played by electrification in the modernization of one of the large gold mines of the world, it seems fitting to mention the part that the quest for gold played in the white man's migration over the globe.

The quest for gold and gold mining have fascinated man from the beginning of civilization. Nothing has inspired the white man more to explore unknown regions than the search for gold. So it is that this searching had much to do with his conquest and exploration of remote parts of the world, and also his migration from the place of his origin to the four quarters of the globe.

In our own country the search for gold was also one of the causes for its rapid development. This is particularly true of the section west of the Mississippi River. The early Spaniards spent much time searching for gold in the South and Southwest.

In 1849 came the great gold rush to California and with it the very rapid settlement of the Pacific Coast country. Men suffered much hardship and faced great dangers in trying to reach this new El Dorado.

The discovery of gold in the Black Hills, by white men, was made by some prospectors who were with General Custer's famous exploring expedition in 1874. At that time the Black Hills were a part of the Sioux Indian Reservation and, therefore, not for white settlement. But as soon as it became known that there was gold in the Black Hills it was impossible to keep the white men out of them although the U. S. army made a diligent effort to do so. So in a short time the Hills were opened to the prospectors.

The Black Hills are located in the Southwest corner of South Dokota. The Hills part of the name is quite misleading because it causes one not familiar with them to underrate their height. As a matter of fact they are real mountains. This is borne out by the fact that the highest point in the United States east of the Rocky Mountains is located in them.

The Homestake Mining Company's plant is located at Lead, South Dakota in the northern part of the Black Hills. The company was incorporated under the laws of California on Nov. 5, 1877. Later on several other companies in the district were consolidated with it making it one of the largest gold mining companies in the world. Measured by the extent of its underground workings it is probably the largest one. If it were possible to place its underground drifts end to end they would make a tunnel about fifty miles long.

The first stamp mill of 80 stamps was started in 1878. The mine has been practically a steady producer ever since that date. Stamps were added to the first mill and other mills were built until 1000 stamps were in steady operation.

From its beginning to date the mine has produced over $200,000,000 worth of gold bullion and paid over $50,000,000 in dividends.

When the Homestake company began operations there were no transmission lines or power stations. But some form of cheap power has generally been necessary to carry on successfully industrial or mining operations. So in those days industrial operations were generally carried on near the source of some cheap power, either near a fuel supply or waterfall. With mining it is different, because it has to be carried on where the ore is located; and generally the ore treatment must also be executed there, as it would not pay to transport the ore very far.

Many mining propositions could not be developed until the days of electric power transmission because there was no suitable power source near them. But fortunately for the Homestake, it is located in a place that had an abundant supply of wood for use as fuel. Steam boilers and engines were installed at the various plants and wood was used as fuel for many years. By the time that the nearby supply was exhausted, railroads had been built into the district and coal was brought in and the use of wood discontinued.

The Homestake had been in operation quite a number of years and had quite an extensive plant before there was any railroad connection with the outside world. Almost from its beginning the company had a narrow-gauge railroad of its own for bringing in wood and timber from the district around Lead. Later on this railroad was bought by one of the lines that built into the district. The little railroad is still in operation.

Before the days of actual railroad connection, the nearest railroad points were Sidney (Neb.) and Cheyenne (Wyo.) on the Union Pacific, and Bismarck (N. D.) on the Northern Pacific. All of the early mining and milling machinery and general supplies had to be hauled into the district by bull teams for a distance of over two hundred miles. The locomotives, rails, etc., for the company's railroad had to be hauled in the same way.

Passengers, mail, and express were carried by stagecoaches. Pony express riders were used for what was known as fast service. Many romantic novels have been written about the exploits of the express riders, stagecoach drivers, and bullwhackers of those days.

It has often been said that the older mining companies were slow to adopt new forms of motive power and communicating systems. That appeared to be so because these companies had well established plants long before the days of electric power plants or transmission lines. But by looking into the history of these companies it will be found that many of them actually helped to develop electric drives for mining and milling operations. The Homestake Company has always replaced old types of machines with new ones as soon as it could be seen that it would be economical to do so. This is borne out by the fact that many hundreds of thousands of dollars worth of machinery has been scrapped, not because it was old but because it was obsolete.

The telegraph was the only commercial device using electricity before the days of the Homestake; but the first model of a telephone was exhibited at the Centennial Exposition in Philadelphia the year the mine was located. Beginning with the year 1876, the invention and development of electrical machines increased rapidly from year to year, but it was still to be a long time before the electric motor was to be a success for large power application.

Probably the first electric circuit of any kind in Lead was a telegraph line built in 1879. This line extended from Cheyenne (Wyo.) through Lead to Deadwood, and the Homestake Office was connected to it. In 1880 another line was built from Ft. Randall on the Missouri River to Deadwood. Both of these lines were built by the U. S. Government.

In 1880 the Father DeSemet Company, now a part of the Homestake, installed telephones in its works and office. The Homestake has had some form of telephone system almost from its beginning. More will be said about the company's telephone and signalling systems later on in the article.

The first dynamo on the company's property was a 75-light Edison machine and it was installed in one of the mills during the winter of 1888. It was purchased by the Hearst Mercantile Company for operating the lights in its store. The lights were used for the first time on Christmas Eve and it was the occasion for quite a celebration.

The store lights created such a good impression that a 150-light Edison dynamo was at once ordered for lighting the mills. It was only a short time until the demand for lights overloaded the two small machines and larger ones were purchased.

Among the early machines installed in the district was an incandescent light dynamo built by the Brush Arc Light Company. Among the illustrations in this article is a picture of this old timer with its ammeter. In those days generators were called "dynamos" and rated in lamp capacity. The standard was a carbon filament lamp of 16 c.p. which consumed one-half ampere at 110 volts.

Up until 1906 there were only a few small motors used around the works and they were d-c. machines operated from the lighting generators. Among them was one that was belted to an electroplating generator for silver-plating the copper mill-plates.

Alternating-current transmission and application for power began with the starting of the Englewood Station in 1906. This is a hydroelectric plant located about four miles from Lead. It utilizes the water from the Hanna Pumping Station and the Peak ditch on its way to Lead. The pressure pipe, or penstock, is of spirally riveted steel with rubber-packed slip joints, and is about three miles long. The static head at the plant is 485 ft. and the power varies between 300 and 400 kw. The generator is a three-phase 60-cycle 11,000-volt machine driven by an overhung impulse water wheel. This machine was among the early ones built for that voltage.

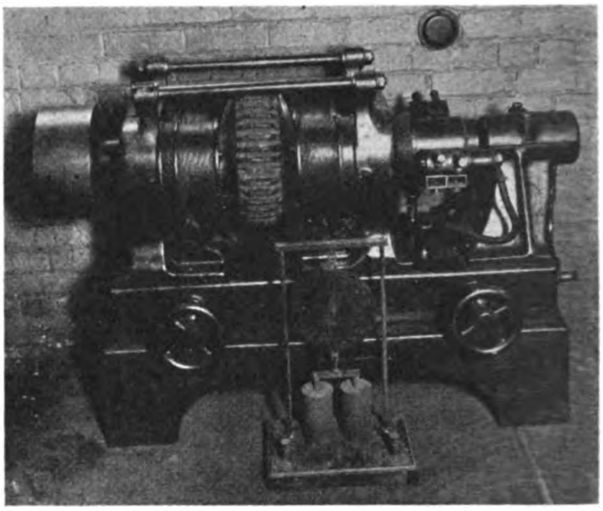

Fig. 1. One of the First Lighting Generators and Ammeters in the Black Hills. These were made by the Brush Arc Light Co.

The power from this station was first used to operate two of the smaller mills, each of 100-stamp capacity. These particular mills were the first chosen for electric drive because they were the most uneconomical from a power standpoint. They were driven by noncondensing slide-valve engines. One of them had two small engines to drive it. It was also very expensive to get fuel to these mills because it had to be handled several times.

The motors for these mills were among the first made for this kind of a drive. They are 440-volt 25-hp. 600-r.p.m. squirrel-cage induction motors with gear-driven countershafts attached to them. On the countershafts are pulleys for driving the stamp-lifting or cam shafts at the low speed of 45 r.p.m. Each motor drives ten stamps as a separate mechanical unit. This kind of a drive is much better for large stamp mills than the steam engines were because it eliminates the long shafts that were necessary with the latter drives.

In stamp mills of this kind the ore is automatically fed to the stamp mortars from overhead bins. Water is added to the ore in the mortars and the water and stamp action reduce the ore to a fine sand. In this way the fine particles of gold are liberated. Mercury is fed into the mortars by hand, a small spoonful being added hourly. The mercury wets the small particles of gold. The product of the stamps passes by gravity over inclined plates. The plates are of copper, plated with silver, and amalgamated with mercury. The mercury-wetted gold particles are caught on the plates. At regular intervals the amalgam is brushed off the plates. When a sufficient amount has been collected it is put into retorts and the mercury distilled off into a condenser where it is recovered. The gold is then melted and cast into large bars and shipped to a United States mint.

At the time of the electrical installation in these mills much doubt existed as to the reliability of electric drives; so the steam plants, line shafts, etc., were left in such manner that engine drive could be resumed on short notice. But it was demonstrated within a year that the continuity of service was far better with the electric drive, although a few short stops were caused by lightning. This installation operated as a separate unit until 1912. It has a record run of 18 months without a single interruption. The generator is still in operation. It has run practically continuously since its installation in 1906, except for occasional short stops for inspection and a few repairs. The generator shaft is still running in the original bearing liners.

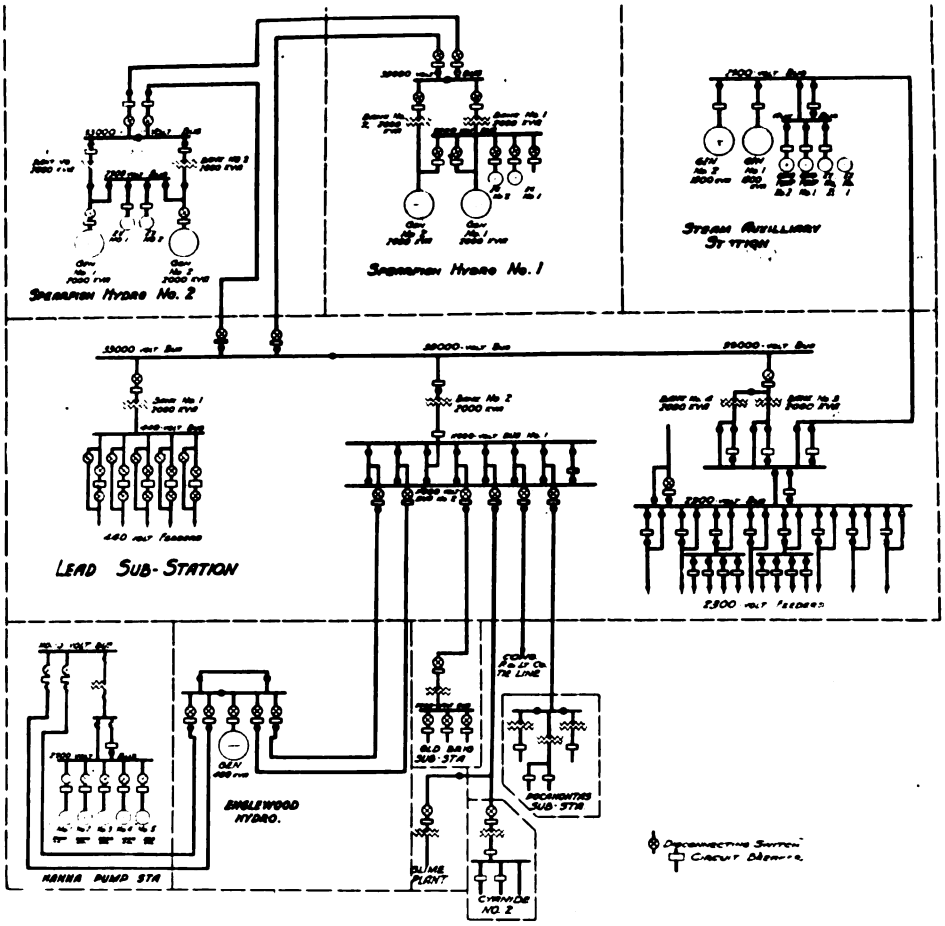
33000 VOLT BUS
GEN No 1 2000 KVA
GEN No 2 2000 KVA
SPEARFISH HYDRO No. 2
33000 VOLT BUS
BANK No 2 2000 KVA
BANK No 1 2000 KVA
GEN No 2 2000 KVA
GEN No 1 2000 KVA
SPEARFISH HYDRO No. 1
2300 VOLT BUS
GEN No 2 1800 KVA
GEN No 1 800 KVA
STEAM AUXILLIARY STATION
33000 VOLT BUS
33000-VOLT BUS
33000-VOLT BUS
BANK No 1 2000 KVA
440 VOLT BUS
440 VOLT FEEDERS
LEAD SUB-STATION
BANK No 2 2000 KVA
2300 VOLT BUS No 1
2300 VOLT BUS No 2
BANK No 4 2000 KVA
BANK No 3 2000 KVA
2300 VOLT BUS
2300 VOLT FEEDERS
HANNA PUMP STA
GEN 400 KVA
ENGLEWOOD HYDRO.
OLD BRIG SUB-STA
CONSOL. PR & LT CO. TIE LINE
POCAHONTAS SUB-STA
SLIME PLANT
CYANIDE NO. 2
DISCONNECTING SWITCH
CIRCUIT BREAKER

Fig. 2. Connection Diagram of the Homestake Electric Power Generation and Distribution System

From 1906 on, all new units added to the company's plant were equipped with electric drives except one new hoisting engine. One of the first new units to be equipped throughout with electric drive was the large slimes treating plant located in Deadwood. This plant is housed by several large buildings that cover considerable ground. Small amounts of power are needed throughout the different buildings, so the use of long steam lines, many small engines and line shafts, was considered much more expensive to operate than electric drive, although the power would have to be purchased for some time.

The object of the slimes plant is to treat the extremely fine sand or slime in the tailings from the stamp mills. In the stamp mills only about 65 per cent of the gold in the ore is extracted. For many years there was no practical way of further recovery from the mill tailings. Then a process was discovered for treating the coarser sands by leaching with a cyanide solution, but it was some years later before a way was discovered to treat the slimes. One of the principal difficulties with slimes treatment was to find a way to set up the slimes in thin enough layers so that they could be easily leached with the cyanide solution. In the slimes plant this is accomplished by means of great, long iron presses into which the slimes flow and set themselves up in very thin vertical layers. After the leaching is finished the tailings are washed out of the presses with an automatic machine. The gold is recovered from the cyanide solution by precipitation with zinc dust. The tailings from the stamp mills are carried by gravity in pipe lines to the treating plants. They are passed through automatic classifiers which separate the coarse sand from the slimes.

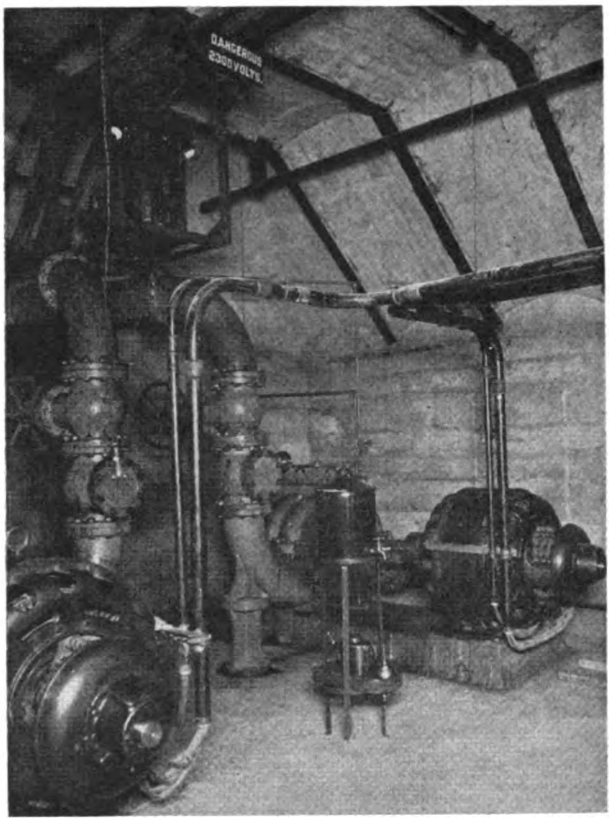

Fig. 3. A Pump Chamber in the Mine ,Showing the Electric Pumps

In 1908 it was decided to change more of the older plants to electric drives. It was also decided to purchase the power for a few years and then build a hydroelectric plant in the Spearfish Canyon. About this time the third stamp mill, containing 160 stamps, was changed over to electric drive. A little later on the two sand treating plants were changed to electric drives. These plants are similar to the slimes plant in that they cover considerable ground and need power in all of the various buildings.

In the sand plants the tailing sand is deposited automatically in large wooden tanks, 45 to 55 ft. in diameter, holding 670 to 1350 tons, and then leached with cyanide solution. After treatment the sand is washed out of the vats with streams of water.

In the spring of 1912 the Spearfish Hydroelectric Plant No. 1 was put into operation. The station is located in the mouth of the Spearfish Canyon. Water for it is diverted from the creek into a tunnel 4½ miles long. From the tunnel the water passes through two 48-in. diameter wood stave pipes, 1200 ft. long, laid in the form of an inverted syphon across a ravine and discharging into a steel header upon which are located four 36-in. diameter stand pipes 54 ft. high. From the header two penstocks, 4800 ft. long, carry the water down to the station. The upper sections of the penstocks are of spirally-riveted steel pipe 34 in. in diameter with rubber-packed slip joints. The intermediate sections are of the same construction but are 32 in. in diameter. The lower sections are of lap welded steel pipe 30 in. in diameter with steel flange joints assembled with bolts.

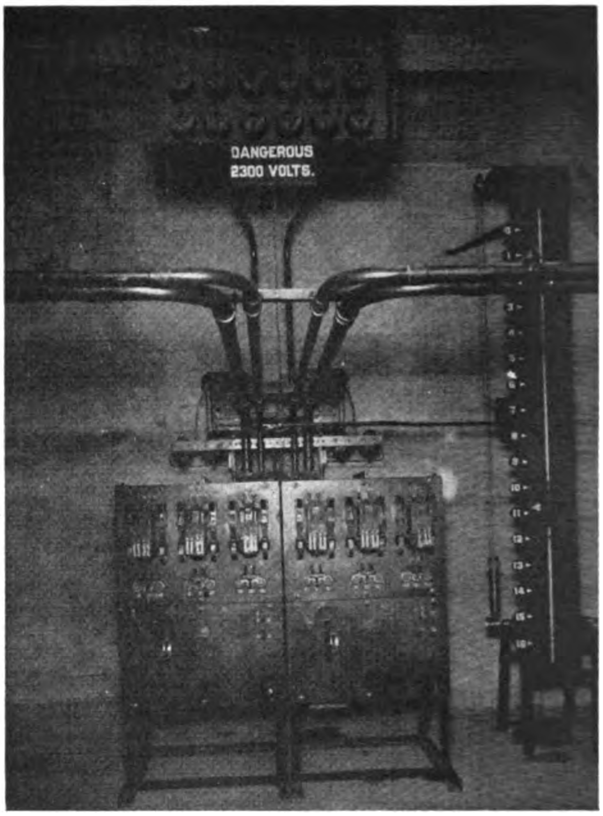

Fig. 4. Automatic Electric Pump Controllers for the Pumps Shown in Fig. 3

In the station are two three-phase 60-cycle 400-r.p.m. 2200-volt 2000-kv-a. generators, each driven by two 1500-hp. overhung water wheels. The static head of the water at the plant is 667 ft. The generator voltage is raised to 33,000 volts for transmission to Lead which is 11 miles distant.

At the time that the Hydro No. 1 plant was built a substation was built in Lead. This station is the control center for the entire Homestake electrical system. All generating stations transmit their power to it, and the local power company's system is also connected to it.

In the station are the transformers necessary for the various transformations. In it is also a suitable switchboard equipped with the customary switch-controls, relays, and indicating and recording meters. All circuits entering or leaving the building are controlled by automatic electrically-operated and remote-controlled oil circuit breakers. Each circuit is also equipped with choke coils and a high grade lightning arrester.

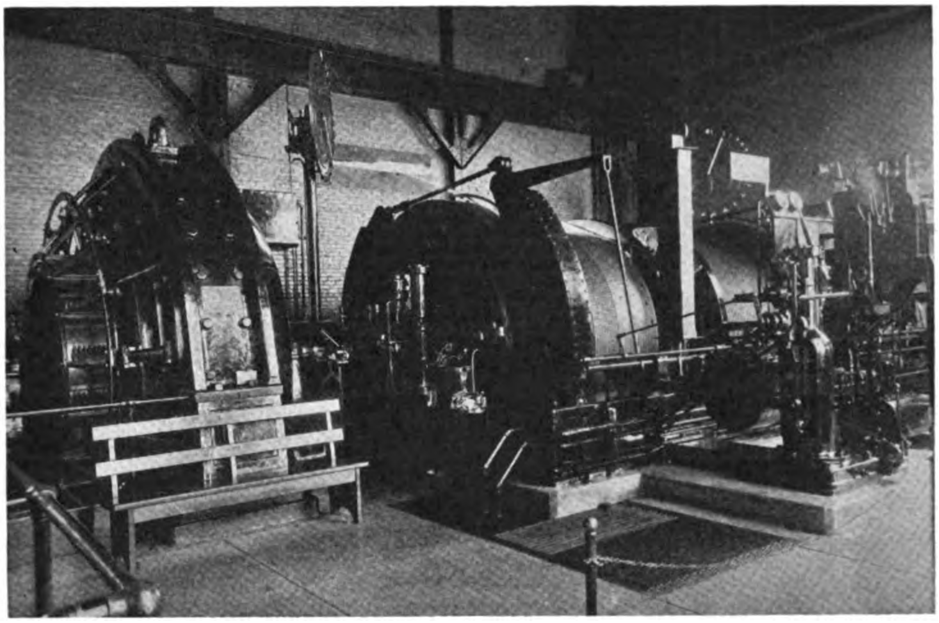

Fig. 5. The Ellison Electric Hoist. This is one of the large hoists of the country

Much of the power, distributed from the substation, is used directly on motors without any further transformation; but to reach outlying plants, a higher voltage is necessary and consequently another transformation is made at those plants. Transformers are also used in the distribution circuits for small motors lowering the voltage to 220 volts for safety and economic reasons. Whenever 220 volts is used three-phase, the center of one transformer secondary is grounded, thereby making it impossible to get more than 190 volts to ground.

All lighting, of course, is done by secondary transformation to 110 volts, only in a few cases was it economical to use the Edison three-wire system. All of the lighting secondaries around the surface plants are grounded in the usual manner, but in the mine, lighting transformers with 55-volt taps are used, and the taps grounded, making it impossible to get more than 55 volts to ground.

Shortly after the Hydro No. 1 plant was completed the three mills that were still being driven by steam engines were changed over to electric power. There were 660 stamps in these mills and each mill was driven by a large condensing Corliss engine. These engines were quite economical, so they were the last to be discarded.

After all of the stamp mills were changed over to electric power, the electrification of the primary crushing plants at the various hoists was undertaken. At that time this was considered somewhat revolutionary and some natural prejudice existed as to the feasibility of the proposition. Ore crushing is a rough job and the Homestake ore being very hard, it was thought by some not to be a suitable thing for motor power. However, some experimental work was carried out and it was found that a 35-hp. wound rotor induction motor was just the ideal thing to drive a No. 6 Gates gyratory crusher. So all crushers were at once changed from steam engine and line shaft drive to individual motor drives.

The object of the crushing plants at the hoists is to crush the ore to quite small pieces before it goes to the stamp mills, breaking it to such size that all of it will pass through holes of 3-in. diameter. From the crushers the ore drops into large bins. It is drawn from chutes in the bottom of the bins into tramcars and hauled in trains to the top of the mills and dumped into their bins.

The water supplying Spearfish Hydro No. 1 station is from a source that varies greatly in volume during the different seasons and from one year to another, so in order to operate the plant economically, it was necessary to load it to at least the average stream flow and make up for the low points with auxiliary steam-electric power. The power was purchased for a few years. Then it became evident that it would be economical to carry the electrification still further.

do away with all of the individual steam plants near Lead, and build a central steam turbine plant.

From the time that the mine attained considerable size until 1902, the pumping was done chiefly by a Cornish pump located in the B. & M. shaft. This installation consisted of a steam engine, at the collar of the shaft, which was connected to the pump rod by means of a connecting rod and bell-crank. The pump rod consisted of 12 by 12-in. sections of timber joined end to end to form a continuous length reaching from the surface to the 800-ft. level. Its great weight was counterbalanced by several rocking counterweights loaded with scrap cast iron. There were several plungers bolted to the rod and operated in vertical cylinders. The pumps were single-acting and the lowest one was on the 800-ft. level.

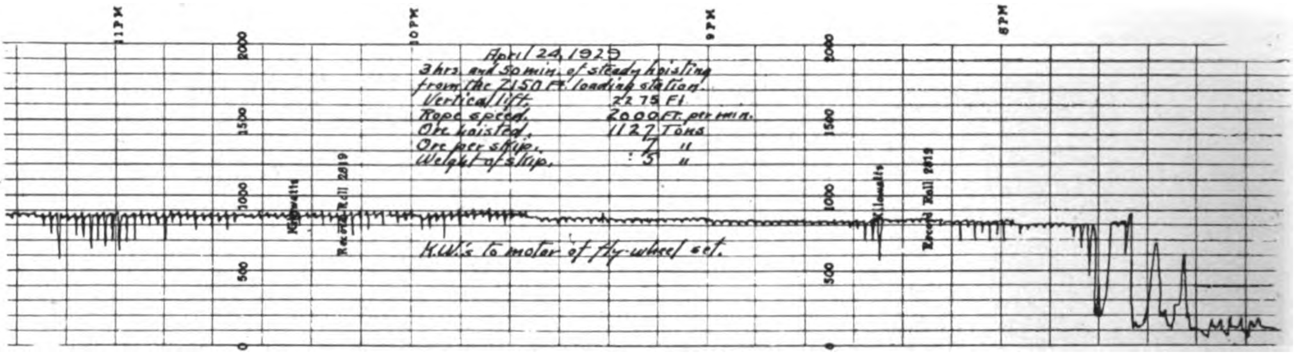

Fig. 6. Curve of Power Input to Motor-generator Set of the Ellison Hoist. Curves like this are quite easy to make when hoisting is done at a uniform rate

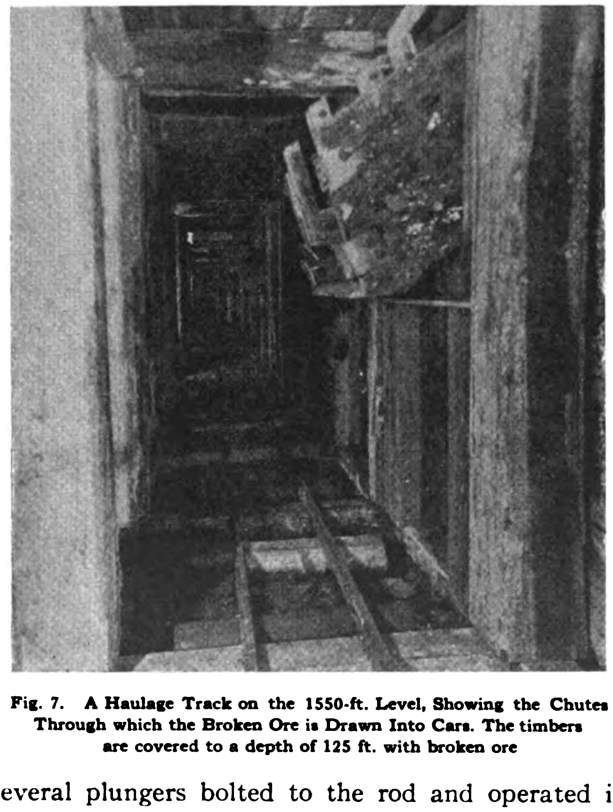

Fig. 7. A Haulage Track on the 1550-ft. Level, Showing the Chutes Through which the Broken Ore is Drawn Into Cars. The timbers are covered to a depth of 125 ft. with broken ore

By 1902 the mine had been extended down to the 1100-ft. level and a condensing steam pump was located on the level near one of the shafts. Steam for the pump was transmitted from a boiler plant on the surface by means of a pipe down the shaft. This pump, supplemented at times by the Cornish pump, did the pumping until the installation of the automatic electric pumps in 1913.

The electric pumps are of the centrifugal type and have three stages. They have a capacity of 1000 gal. per min. against a 325-ft. head. Each pump is direct connected to a 125-hp. 2200-volt 1740-r.p.m. wound-rotor induction motor. The motors are controlled automatically by suitable controllers operated by floats in the pump sumps. The pumps are located in chambers 300 ft. apart vertically. They are in dupli-

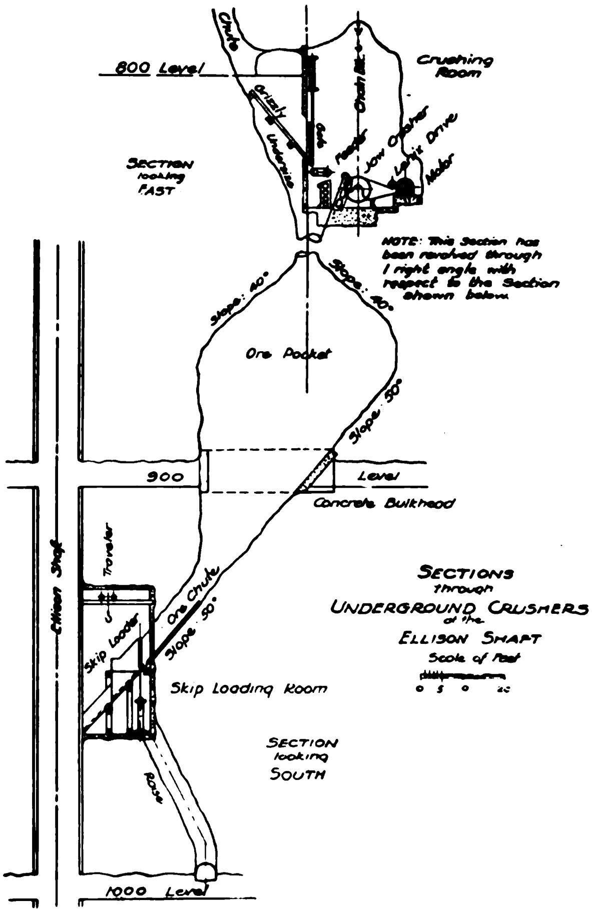
Chute
800 Level
Crushing Room
Grizzly
Undersize
Gate
Chain
Feeder
Jaw Crusher
Lenix Drive
Motor
Section looking East
NOTE: This Section has been revolved through 1 right angle with respect to the Section shown below
Slope: 40°
Slope: 40°
Ore Pocket
Slope: 50°
900
Level
Concrete Bulkhead
Ellison Shaft
Traveler
Ore Chute
Slope: 50°
Skip Loader
Skip Loading Room
Sections through Underground Crushers of the Ellison Shaft
Scale of Feet
0 5 10 20
Section looking South
Raise
1000 Level

Fig. 8. Cross-sectional Elevation of an Ore Crusher Room, Ore Pocket, and Skip Loading Station in the Mine at the Ellison Shaft

cate in each chamber and can be operated simultaneously or separately as desired or necessary. Down to the 1400-ft. level they are located at the B. & M. shaft and below that are located at the Ellison shaft. These two shafts are the principal ones operated by the company. On the lower levels the pumps are driven by squirrel-cage motors, it having been found that they do as well as the more expensive type.

The pumping station for supplying the major part of the water for milling operations was the next plant to be changed to electric drive. It is located about ten miles from Lead. This was another plant that had been built before electric power transmission was developed to any great extent. It was quite an expensive plant to operate because, in addition to the regular engine and boiler room attendant expense, the coal had to be brought over quite a long spur from the main line of the railroad.

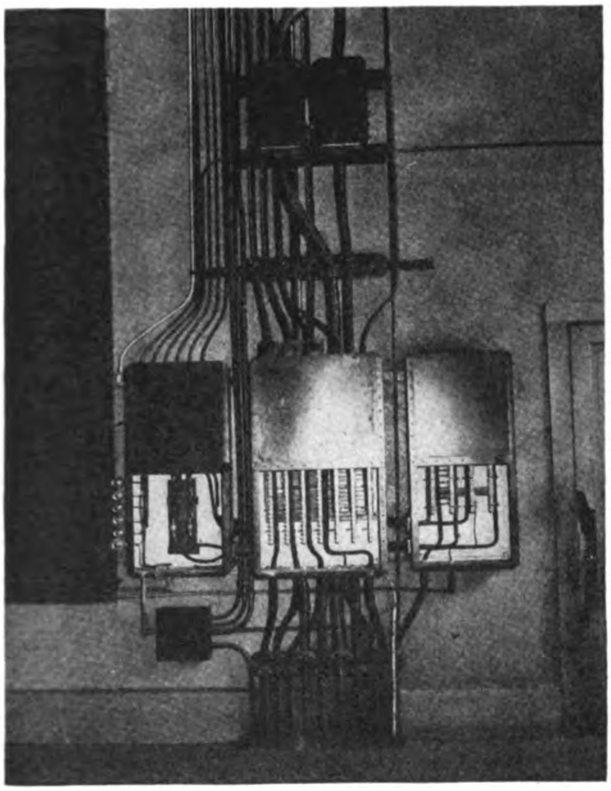

Fig. 9. Electric Power, Light, Signal, and Telephone Cables at the Collar of the Ellison Shaft. From this point they pass on down the shaft

There are five pumps, all of the centrifugal type, for pumping against a 400-ft. head in the station. Each pump is direct-connected to a 2200-volt wound-rotor induction motor which is controlled by a manually operated controller. There are three 2000-gal. pumps with 300-hp. motors, one 1000-gal. pump with a 150-hp. motor and one 500-gal. pump with a 75-hp. motor. With this set of pumps there is some reserve capacity and a combination can always be selected to deliver the quantity of water needed. The capacity of the plant is over ten million gallons per day which would be sufficient to supply quite a large city.

The Steam Turbine Station began operating in 1916. It is located across the street from the Lead substation. In the station are two 1800-kw. 3600-r.p.m. turbines, each connected to a 1500-kv-a. 2300-volt generator.

Early in 1918 a second hydroelectric plant, using Spearfish Creek water, began operating. This plant is located about ten miles up the canyon from the No. 1 plant. It has the same size and kind of station equipment and penstocks as the No. 1 plant, but the head is a little less, being 548 ft. Instead of the water conduit to the penstocks being a tunnel, it is a wood stave pipe. The pipe is four and seven-tenths miles long and most of it is 52 in. in diameter.

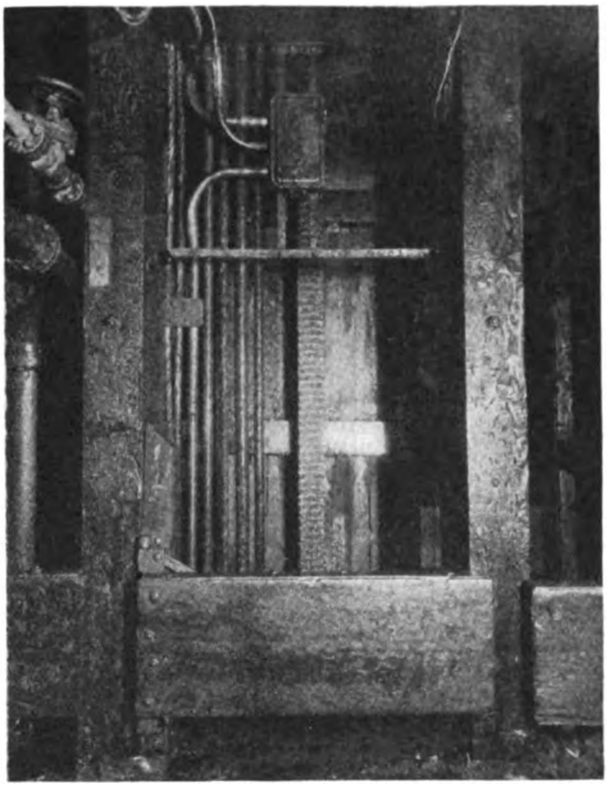

Fig. 10. Electric Cables in the Ellison Shaft at One of the Levels or Stations. A shaft junction box is shown in the upper part of the picture

During the next few years several more steam-engine-driven machines were changed to electric power. Among them was an air compressor, delivering air at a pressure 900 lb. per sq. in., for driving haulage locomotives. The fly-wheel on this machine was replaced by a sheave-wheel for rope drive connection to a 750-hp. 2200-volt synchronous motor. Two of the smaller hoists were also changed to electric power. These hoists were driven by twin-cylinder engines geared to the winding apparatus. The connecting rods and crank pins were removed and a ring gear shrunk onto one of the crank disks of each set and a 200-hp. 2200-volt motor geared to it.

The changing of more of the old air compressors, delivering air at 90 lb. per sq. in. pressure, for driving rock drills, to electric drive was considered to be too expensive and also impractical on account of the large amount of floor space required. So new air compressors with direct-connected synchronous motors were installed and the old ones scrapped. The motors on the compressors vary in size from 500 to 1000 hp.

During 1921 a new electric hoist and ore crushing plant were installed at the Ellison shaft. The hoist is quite large and is of the direct current type with the Ilgner-Ward-Leonard system of control. The winding end consists of two cylindrical drums mounted on a shaft and attached to it by multiple-jaw disk clutches. A 1400-hp. motor is direct-connected to the drum shaft. The full speed of the motor is 63½ r.p.m., giving a rope speed of 2000 ft. per min. on the 10-ft. drums.

The motor-generator consists of a 1200-hp. 2200-volt wound-rotor induction motor direct-connected to a 33-ton steel-plate fly-wheel and an 1100-kw. d-c. generator, and also an exciter for the generator and hoist motor fields. The input to the induction motor is controlled by a liquid slip regulator controlled by a torque motor operated by current transformers in the stator leads.

The hoist and motor-generator set are fully equipped with automatic safety devices. For instance, it is impossible to pull a skip or cage up to the sheave wheels or lower them into the sump; it is impossible to overspeed either set; and the hoist will be automatically retarded and stopped as a cage or skip approaches the top or sump.

The object of the extremely heavy fly-wheel on the motor-generator set is to transform the violently fluctuating power demand of the hoist motor to a practically uniform average demand on the power supplying system. The power demand during acceleration from the 2200-ft. level is 2500 hp., which suddenly drops to 1350 hp. when full speed is attained; and during full-speed operation it drops uniformly until it reaches 600 hp. at the point of retardation. Instead of retarding by means of the brakes, the motor is caused to function as a generator and transmit power to the fly-wheel set. At the beginning of retardation the regeneration reaches a value of 1050 hp., and gradually drops to zero as the hoist comes to rest, the maximum variation being from plus 2500 to minus 1050, or 3550 hp. For hoisting from the 3200-ft. level, when that depth is reached, it has been calculated that the variation will be 3900 hp. It is easily understood that such great power demand variations could not be tolerated on any but very large power systems, and that, therefore, it was very necessary that an equalizer be used in order to operate a hoist of this size on the company's system.

The equalizing action of the fly-wheel set is brought about by limiting the maximum power input to the induction motor to the average required to hoist from a given level at a constant rate. Then the varying demands of the hoist motor are taken care of by the exchange of energy with the fly-wheel through speed variations. When hoisting is carried on at a uniform rate, the regulator can easily be set so that the power demand from the line is almost absolutely uniform. This may be seen from one of the illustrations in this

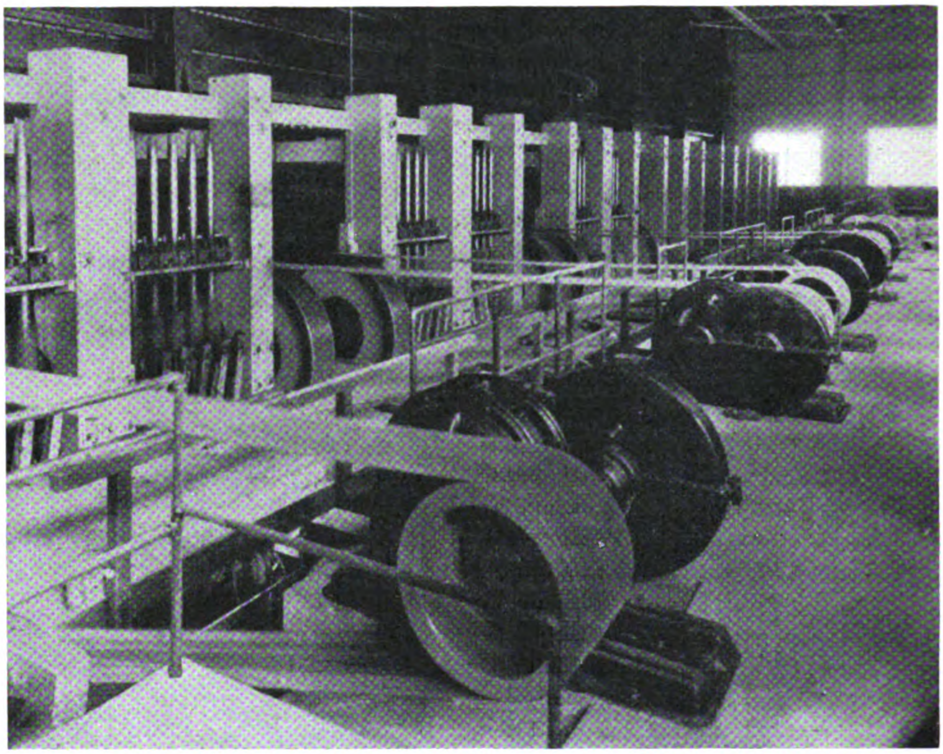

Fig. 11. One of the Stamp Motor Floors in the South Mill, Showing the Back-geared Motors Belted to the Cam or Stamp-lifting Shaft Pulleys

article. The picture is a section of a chart from the graphic watt meter connected in the induction motor circuit. The operator did not know he was doing work for exhibition at the time the chart was being made.

The primary crushing at the Ellison shaft is done in the mine as the ore passes to the skip loading bins. For this purpose large jaw crushers are used and each one is driven by a 125-hp. 2200-volt wound-rotor motor. From the bins the ore is loaded into the skips by a machine that is under manual control but which automatically measures the correct load, about 7 tons, for each skip. When the skips reach the surface they are automatically dumped into a bin. From this bin the ore is carried, by conveyors, to a system of screens and gyratory crushers and the oversized ore crushed. From these crushers the ore drops into bins from which it is hauled to the mills.

During the time the electric hoist was being installed at the Ellison shaft, a much more extensive and better electric cable system was installed in the shaft. There are two main cables, one for power and one for lighting service. The conductors of the power cable have a cross-section of 350,000 cir. mil and those of the lighting cable are of No. 2 B. & S. gauge. The individual conductors of the cables are rubber insulated, taped, assembled with jute in a spiral lay and covered with jute-covered galvanized steel wire armor. Both cables are for 2300-volt three-phase service to three distribution or substations. The cables are supported with cast-iron clamps placed on 12-ft. centers and attached to the shaft timbers with lag screws. They are suspended in the shaft in continuous lengths between the different substations and the ends run into the stations to avoid joints in the shaft.

It was somewhat of a task to lower these cables into the shaft, because they are quite heavy, the heaviest section weighing 12,100 lb., and care had to be exercised not to subject the insulation to excessive crushing pressure while passing it over diverting sheaves. In clamping the cables to the timbers the uneven stretch, caused by tension, had to be taken care of, and also a small amount of slack left for contraction during probable subsequent lower temperatures.

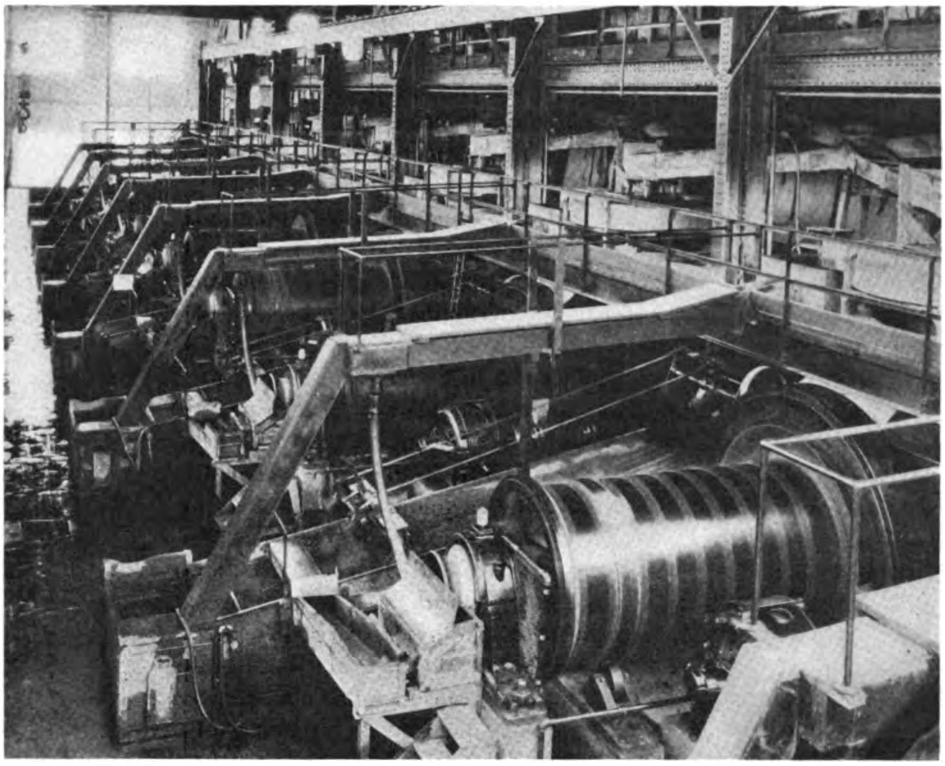

Fig. 12. View of the Large Motor Driven Rod or Grinding Machines in the South Mill

The substation chambers are concrete lined and provided with latticed steel doors that are kept locked. In each station is a bus for 2300-volt power service and one for 2300-volt lighting transformer service. The main cables are connected to their respective buses through disconnecting switches. All feeder and tap connections to the buses are made through disconnecting switches and expulsion fuses. The 2300-volt power distribution feeders are rubber-covered wires run in iron conduit. In the shaft the conduits are held in place by cast-iron clamps. Cast-iron junction boxes are connected into the conduits at intermediate levels for connecting conduits and feeders for those levels. The vertical wires are supported by wooden clamps bolted to projections in the boxes. For small motors, 220-volt three-phase service is supplied from transformers located in the substations. In each station is located a transformer for supplying 110-volt single-phase service for lighting. Each transformer serves a section of the mine through a number of feeders, each of which is separately fused.

In these stations are also located the terminal connecting boards for the shaft telephone cables. It is to these boards that connections for the telephones are made, and the lines for the intermediate levels are in a system of small conduit in the shaft. Each telephone in the mine is served by a separate circuit from the exchange. The shaft cables for telephone service consist of rubber-covered wires protected by a steel wire armor.

When this cable and secondary feeder system became quite extensive, considerable trouble was experienced by insulation failures of the smaller feeders on the lower levels. It was found that these failures were due to high transient voltages caused by switching operations or other disturbances on the 2300-volt system, sometimes a considerable distance from the Ellison shaft. Lightning arresters were then connected to all underground substation buses and no more feeder failures occurred.

At first thought, this underground system will seem quite elaborate, but when it is considered that the shaft is one-half mile deep and serves many levels, also that it will probably be greatly extended, it will seem to be justifiable. In a system of like size and extent located on the surface, about as much care would be exercised with its installation, although the operating conditions would be much less severe than those existing in the mine.

In 1922 a new mill was placed in operation by the company. This mill is probably one of the largest and most up-to-date gold ore milling plants in the world today. It was built to replace several of the older mills and in that way concentrate operations and reduce mill-costs very much. In this mill the ore is not reduced to a sand fine enough for treatment by the stamps alone but large rod mills are used to do the final grinding of the oversize before the sand passes on to the plates. The mercury is fed into the rod mills instead of the stamp mortars. The gold is caught and recovered from plates in the same manner as in the older mills.

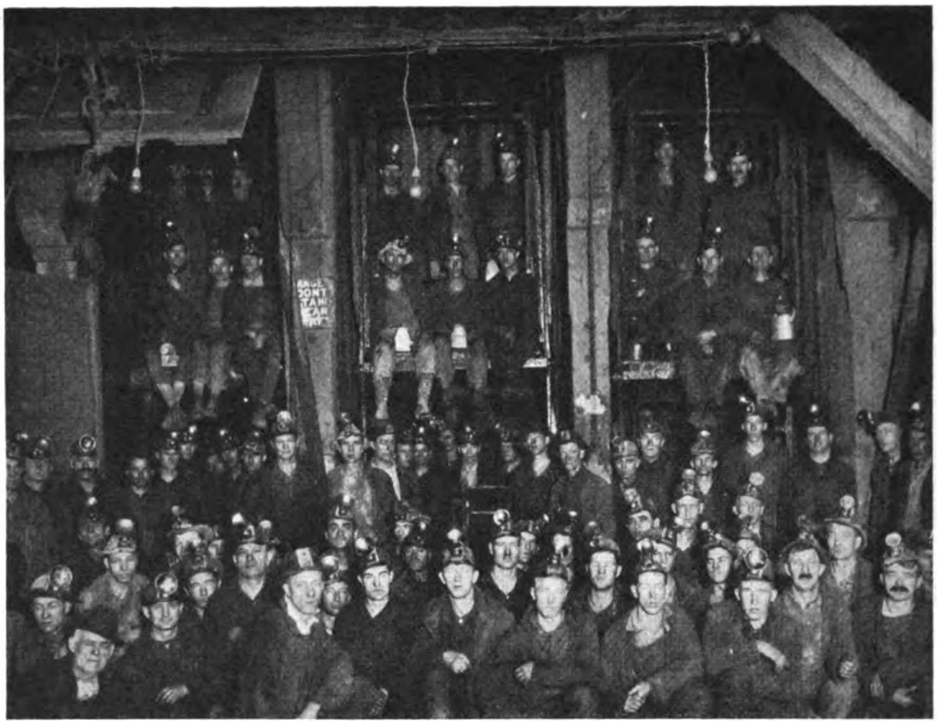

Fig. 13. Miners on the 2300-ft. Level Ready to be Hoisted to the Surface. The picture also shows the shaft timbering and cages (elevators) on which the men ride

In this mill the stamps are much heavier than those in the other mills and a 25-hp. backgeared motor is used to drive five stamps as a unit. There are 24 five-stamp batteries in the mill. There are eight rod mills, each of which is driven by a 100-hp. wound-rotor motor geared to it. The grinding rods are of all sizes up to three inches in diameter. They are made of hard steel so that they will break up into small pieces when they become slender instead of rolling up into a mat.

Before the sand passes from the mill to the cyanide plant, it is classified and the coarsest sand reground in four ball mills. These mills are the same in principal as the rod mills but hard pebbles or steel balls are used as grinders. Each of the ball mills is driven by a 35-hp. wound-rotor motor. Each of the twelve mills is equipped with a classifier that returns the oversize sand to it for regrinding. Each classifier is driven by a small motor.

Up until a few years ago there had been very little need for artificial or forced ventilation in the mine, and what was needed was done by small motor-driven fans located in the mine. As the mine workings became more extensive a ventilating raise was driven from the lower levels to the surface. A large ventilating fan was installed on the surface and connected to the raise. The fan has a capacity of 225,000 cu. ft. of air per minute against a $4\frac{1}{4}$-in. water-gauge pressure. It is belt driven by a 300-hp. 2200-volt squirrel-cage induction motor. The fan action is reversible in that by manipulation of fan-house doors it can be made to draw air out or force it into the mine. So far it has always been used to draw the air out. There are also a few motor-driven fans in the mine for supplying supplemental ventilation.

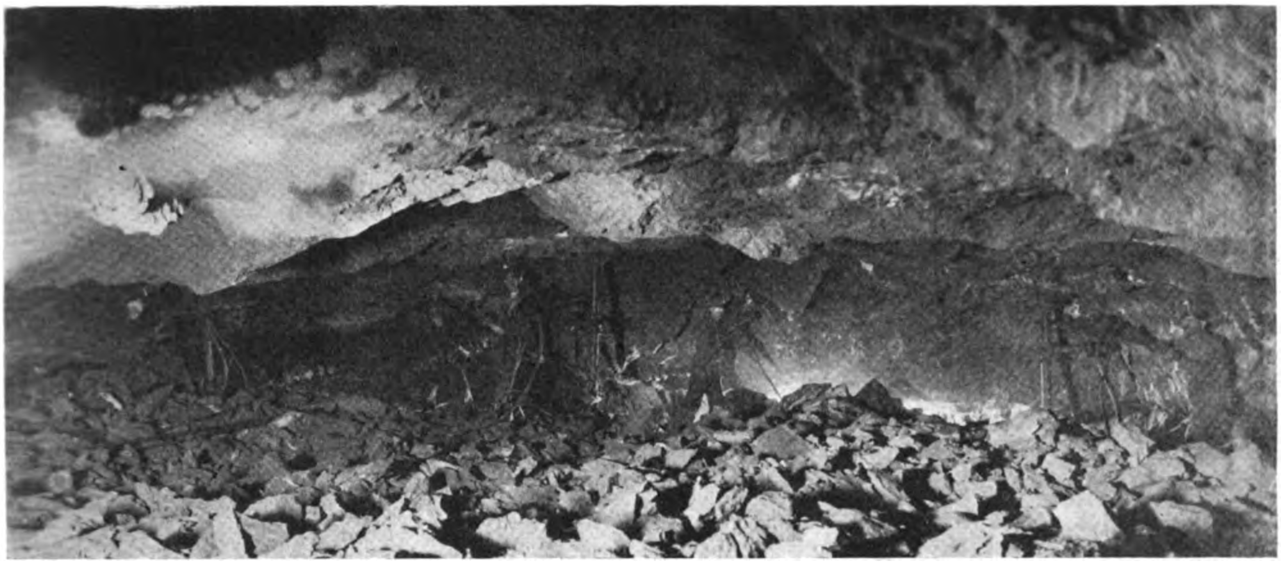

Fig. 14. Miners Operating the Compressed-air Ore Drills in a Stope or Chamber. The broken ore is used as a platform on which to work

Electrically-driven rock drilling machines have been tried in the mine, experimentally, several times. They were more economical in power consumption per foot of hole drilled than the air machines, but their overall efficiency was much less because, while they required the same amount of labor to operate, the footage drilled per day per machine was much less. In addition they were more expensive, heavier, and because of the nature of their construction, had to be handled more carefully.

The ore in the Homestake is quite hard and, therefore, somewhat difficult to drill and break. There are 3000 drills dulled and 2500 lb. of dynamite used each day to drill and break ore. About 4000 tons of ore are handled per day but much of this is taken from a caving district and requires very little drilling or shooting.

Electric haulage in the mine has been considered and, while the power required per ton-mile would be less than with air locomotives, the additional expense incidental to the operation of the electric installation would be much more than the cost of the power saved. To one not acquainted with the mine this will seem strange, but it will be different when it is understood that there are many miles of track, all of very narrow gauge (18 inches), and much of the track not regularly used, but must be maintained for use at any time, as the haulage routes are changed. With a trolley system this would mean much bare wire that would need to be installed and maintained in a safe and substantial manner. It would also require an extensive feeder system and quite a number of motor-generator sets for a mine of so many levels, each of great extent. Storage battery locomotives were considered unsuitable for such an extensive haulage system of very narrow gauge track.

Horses were used for a long time for ore hauling in the mine but as the tonnage increased this form of motive power became too slow and expensive. At the time the air locomotives were introduced there were 100 horses in the mine, many of them having been deep underground for many years.

There are about 6000 tons of rock hauled underground every day, 4000 tons of this being ore and the balance waste that is used for filling empty stopes. As this amount of rock would fill 120 standard gauge cars of 50 tons each, it can be understood that its haulage is quite a task when carried on underground in one-ton cars.

Until 1916 all of the shaft signaling between cagemen and the engineers was done by means of mechanically-operated bells. The bells of course were located near the engineers and were sounded by pulling on steel cables suspended in the shafts. Some of the shafts were reaching such great depth that the signal lines were becoming unwieldy and difficult to keep in adjustment, due to expansion and contraction. An electric signal system was then installed for the skip compartments of the B. & M. shaft. This system consists of a pair of wires in iron conduit in each compartment connecting with switch boxes located at suitable intervals. A steel wire rope is attached to each switch and extends down to the next box. The switches operate 110 volt a-c., single stroke bells located on the engineer's platform.

A little later a similar system was installed for the cage compartments of this shaft. In the latter installation, switch boxes were located a short distance above each station and, as there is only one cage with a counterweight operating in this section, short Manila ropes are used with the switches in the cage compartment, and the signaling between levels is done by means of long wire ropes connected to the switches in the counterweight compartment.

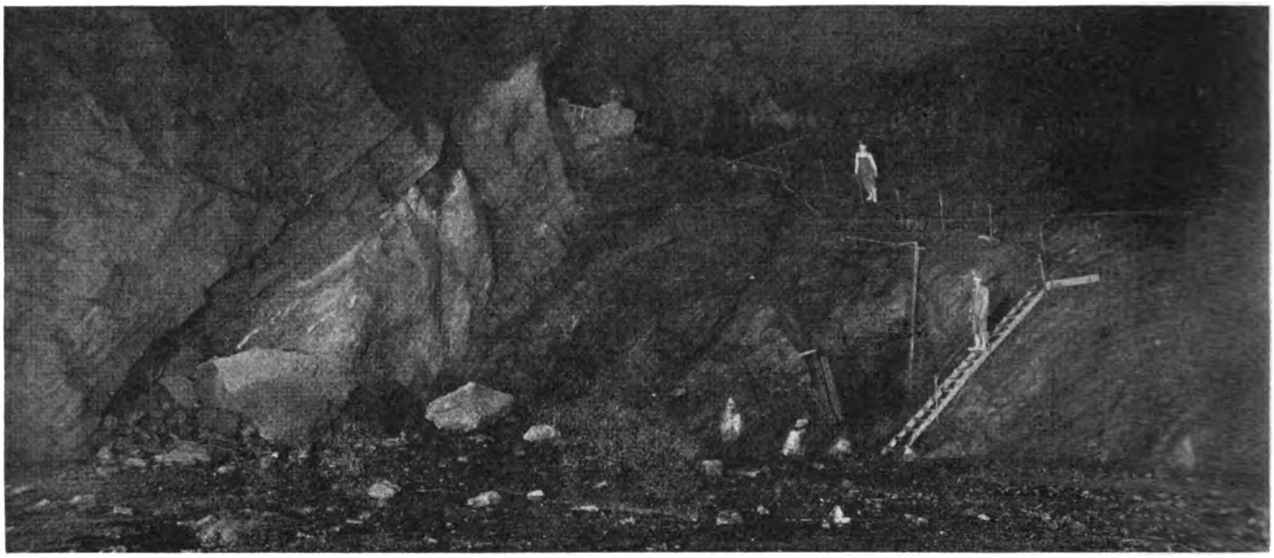

Fig. 15. A Stope or Chamber from which the Ore Has Been Removed. The size of this stope is 60 ft. wide, 80 ft. long, and 75 ft. high

Later on, an electric signaling system was installed in the Ellison shaft. This system is an improvement over that used in the B. & M. shaft in that in each compartment a separate wire is run from each switch to an annuniciator located on the engineer's platform. At each level or station a switch is located a short distance above the level in each compartment and from each switch is hung a steel wire rope reaching down to the next switch.

With this system the engineer can always see from which level a signal is transmitted. This is of much importance because if he receives a signal from a station other than the one at which the skip or cage is located he has positive indication that it is false. False signals occur occasionally, due to objects which, falling in a shaft, strike a switch rope or an inexperienced man reaches into the shaft and pulls a switch rope. The annunicators are automatically reset by a switch attached to the hoist control lever. The signal wires in the shaft are in the form of a cable composed of rubber-covered wires covered by a steel wire armor. The signal and telephone wires in the shaft would make a continuous length of forty miles.

For many years the calling of the cage tenders to the different levels was done by air-operated whistles located in the shaft and operated by a wire cable. Recently an electric call system was installed. This consists of horns located in the shaft at each level and controlled by pull-switches on the stations.

When the ore tramming first became quite congested on some of the levels, flagmen were employed to keep the trains moving rapidly with safety. This was quite expensive and also unsatisfactory because on some levels several flagmen were required and, being located some distance apart, they could not act in unison. This led to the development of an electric signaling system by means of different colored lamps operated by specially designed switches. On some of the levels this system has become very extensive and somewhat involved, but is operating very satisfactorily. The system is quite economical because the trainmen operate the signal, making the employment of flagmen unnecessary.

All of the apparatus for the various signaling systems was developed and built by the company because it could not be purchased. That is quite natural because shafts as a general thing are quite wet and anything located in them soon becomes covered with mud and soaked with water. Heaters are quite often used to keep some of the electrical apparatus dry. In each horn box, and also in each mine telephone, there is a small heater. These little heaters only consume six watts each but they serve the purpose very well. Somewhat larger heaters are put on some of the motors in the mine.

As was said before, the company had some form of telephone system almost from its beginning. At first there was only a single circuit with many telephones connected to it. Later on, a 100-drop switchboard was installed and all telephones connected to it by individual lines except a few telephones in the outlying districts, which were served by party lines. Soon after the installation of the telephone central station it became necessary to add another 100-drop section to the switchboard. At present all of the plants, offices and mine are well equipped with telephones. The residences of the department heads and some of the foremen are also connected to the company's exchange. In the mine there is a telephone on every level, both at the B. & M. and Ellison shafts. In some of the larger plants there are interplant telephone systems in addition to the exchange connections. There are also independent telephone systems between the skip loading stations and the hoisting engineers at both the Ellison and the B. & M. shafts.

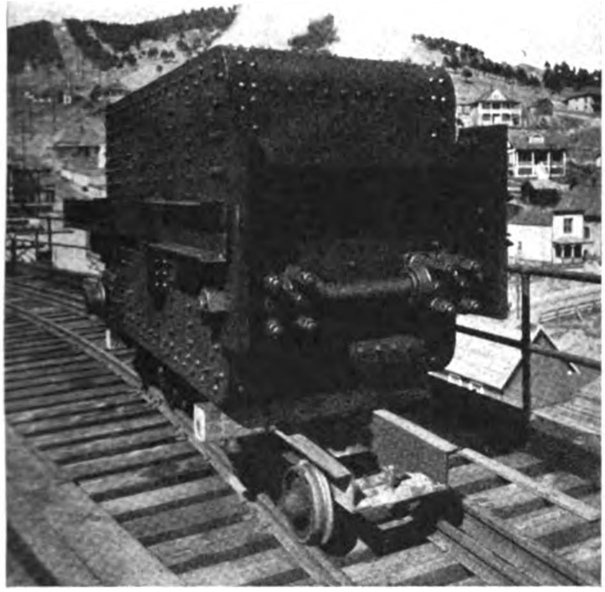

Fig. 16. One of the Automatically Dumping Skips for Ore Hoisting in the Ellison Shaft. Two of these skips are used in counter-blance. Each weighs five tons and has a capacity of seven tons of ore

As mining, milling, and treatment of ore are naturally rough processes, any apparatus used therewith must be of rugged construction. This naturally applies in particular to the electrical apparatus also. It must not only be able to stand rough use, but much of it must be so contructed that it will operate in wet places or in a very humid atmosphere. Many of the control devices have been designed and built locally and others have been altered to suit local conditions. All motor control devices are enclosed in steel cabinets or compartments. Some of them are equipped with electric heaters to keep them dry.

A great effort is made to protect all apparatus with controls adjusted to prevent extreme overloads and burnouts; but of course the greatest effort is made to prevent accidents to human beings. Over a period of many years the average number of motor burnouts per year has not been over two or three. The company has been very fortunate in that there have been very few accidents from electrical causes. In all of the years of electric operation there has not been a fatal accident, and only two serious ones that needed hospital attention were caused by its electrical system.

The electrification of the Homestake plant has not only helped to keep the plant up to modern standards but also to greatly reduce operating costs. Operating costs are of vital importance to gold mining companies because, although they have no competition to meet, the price of their produce is no higher today than it ever was. As the cost of labor and materials have increased greatly during the last few years, it has become necessary for gold mining companies to reduce operating costs to a minimum in order to survive. Rising costs have caused quite a few of these companies to suspend operation during the past few years, leaving only the large ones or those having high grade ore in operation.

The Homestake ore is what is known as low grade and has averaged around $4.60 per ton during the last few years. This grade of ore must be handled on a large scale and in a most economical manner in order to make it profitable. The mills and secondary treating plants operate continuously, *i.e.*, 24 hours per day and every day in the year.

In reviewing the progressive application of electricity to the operations of a company only a little over fifty years old, the comparatively recent application, to practical uses, of this mysterious agent is again brought to mind. Another thing that is brought to mind is that, at first, the development was quite slow; but later on increased successively faster and faster until the social and industrial systems of today would be impossible without the use of electricity.

Electric Motors in Main Oil Pipe Line Pumping

Economies of Various Types of Drive—Analysis of Motor-driven Centrifugal and Reciprocating Pumps—Centrifugal Pump Operation—Automatic Control

By G. R. PROUT
Industrial Department, Dallas Office, General Electric Company

THE oil pipe line industry has until recent years been dependent on oil engines of the Diesel or semi-Diesel types or on steam engines for driving pipe line pumps. During the past few years, however, and particularly the last two years, the application of electric motors by pipe line companies for driving main line oil pumps has been very rapid. There is at the present time over 115,000 hp. in motors driving main oil pipe line pumps in Texas, Oklahoma, and Arkansas alone, and this has nearly all been installed since January 1, 1927. There are three companies that now have over 20,000 hp. each in such equipment and the total of electric motor horsepower for these three companies is about 70,000 hp.

There are several reasons for this development, the two most important of which are:

(1). The power companies have increased capacities in their generating stations, and their transmission lines have spread out so that new electrical energy, from reliable sources, is available over a network of transmission lines which cover or can readily be made to cover most of the territory over which the oil must pass on its way from the area of production to the refinery or market.

(2). Motor-driven centrifugal pump units have been developed which handle oil at high pressures and capacities at good efficiencies.

When operating at high heads, the centrifugal pump is essentially a high-speed machine, which accounts for its development with motor drive. Consequently, of the 115,000 hp. in motors driving main line pumps, about 80,000 hp. is direct connected to centrifugal pumps. The remaining 35,000 hp. is driving reciprocating pumps.

There is of course, in addition to the foregoing, a considerable capacity in motor-driven reciprocating and centrifugal pumps installed in gathering systems.

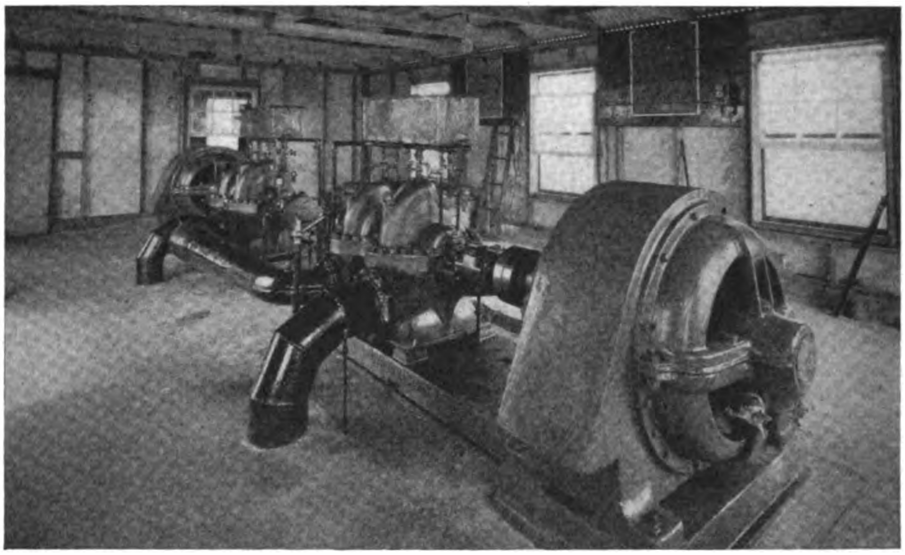

Fig. 1. Two 300-hp. 1800-r.p.m. 440-volt Squirrel-cage Induction Motors Driving Bryon Jackson Pumps (Oklahoma Pipe Line Company, Henryetta, Okla.)

Economics

Naturally, the question arises as to the economics of the problem. How can a pipe line company afford to purchase electrical energy for driving a motor when oil, which can be used as fuel in oil engines, is passing through the pumping station?

The answer is involved, and a complete volume would be required to cover the various conditions. Since there are so many factors involved we shall consider only a few.

The total pumping cost is made up of the following:

(1). Fixed charges which include interest, depreciation, taxes, and insurance.

(2). Operating costs which include fuel or power costs, labor, maintenance, lubricating oils, waste, etc.

(3). Overhead charges for management, supervision, etc.

The last factor mentioned will of course be approximately the same regardless of the type of equipment used, and so can be disregarded in a comparison.

The fixed charges depend upon first cost, salvage value, rate of interest on the investment, and the tax and insurance rates.

The motor-driven pumping station, whether centrifugal or reciprocating pumps are used, has a much lower first cost than the oil-engine-driven or steam-engine-driven pumping station. It also has a lower loss in non-salvable material, hence the fixed charges are much less for motor-driven stations.

To give some idea of the difference in investment required, as well as the values of salvable equipment and non-salvable material, there is presented in Table I the approximate costs of a motor-driven centrifugal pumping station, a motor-driven reciprocating station, and oil engine driven reciprocating pumping station having a capacity of approximately 30,000 bbl. per day at a head of approximately 600 lb. per sq. in. Each station has three units, one of which is a spare.

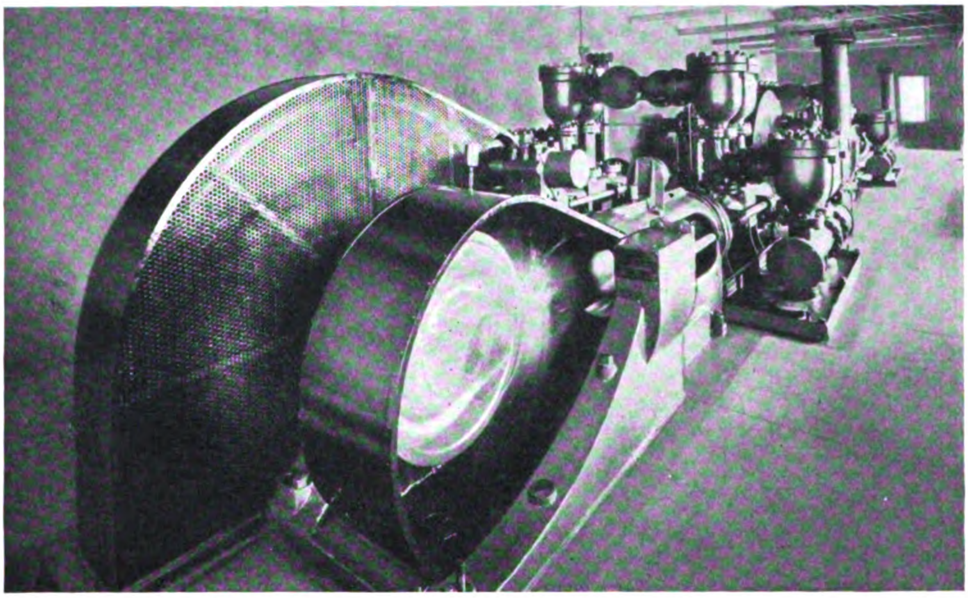

Fig. 2. Two National Transit Pumps Driven by 200-hp. 2200-volt Squirrel-cage Induction Motors (Sinclair Pipe Line Company, Seminole, Okla.)

TABLE I

	Motor-driven Centrifugal Station	Motor-driven Reciprocating Station	Oil Engine Driven Reciprocating Station
First cost	$45,000	$80,000	$200,000
First cost of salvable machinery	16,500	40,000	100,000
First cost of non-salvable material, labor, etc.	28,500	40,000	100,000

The first-cost values in Table I cover the equipment, buildings, operators' houses, manifolds, valves, piping, and installation. The type of building, the type of houses built for operators, the design of manifold, and the number of tanks can vary the costs, but it is believed that those given are fair estimates for average stations of the types considered.

The amount to be charged for depreciation of course will depend on the number of years the station is in operation and the value of the salvable equipment at the end of this period.

The hazard of investment in any industry is one of the determining factors in fixing the rate of return expected by capital. In the pipe line industry the hazard may be greater than that in some other industries, on the one hand, but the prospects of a large rate of return, on the other hand, perhaps balances this hazard and sufficient capital is usually available. Nevertheless, it is undoubtedly a decided advantage to keep the first cost down and the salvage value up as this always makes for more liquid assets. The motor-driven station has a decided advantage in this respect.

The motor-driven centrifugal station has another advantage in that the equipment is comparatively small and light and can be readily moved to a new location.

The operating costs, as has been stated, consist of fuel or power costs, labor, maintenance, lubricating oils, waste, etc. The fuel cost for the oil-engine station is of course low, and charges should be made for this oil only at the price of oil at the delivery end of the line. The power cost for the motor-driven station is a great deal higher than the fuel cost of the oil-engine station, and is the largest operating cost of the motor-driven station.

The labor cost for the oil-engine station is usually twice as high as the labor charge for motor-driven stations.

The lubricating oil cost for the oil-engine-driven station is much higher than that for either the motor-driven reciprocating pump or the motor-driven centrifugal pump station. The lubricating oil cost for the motor-driven centrifugal pump station is exceedingly low and can almost be neglected.

A factor which is of great importance in the operating cost of a station is the amount of oil handled by a pipe line over a period of years. If the amount decreases year after year, the fuel or power costs decrease; and since the power cost in the motor-driven station is such a large proportion of the operating cost, the reduction in this operating cost is much greater than in the case of the oil engine station where the fuel cost is low and is but a small fraction of the total operating cost.

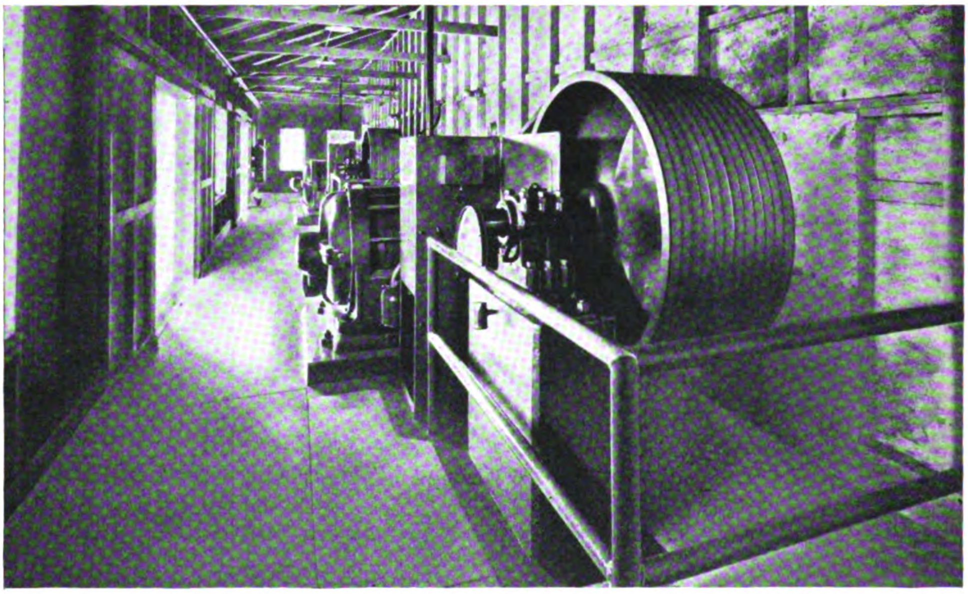

Fig. 3. Two 200-hp. 720-r.p.m. 2200-volt Motors Driving the National Transit Pumps Shown in Fig. 2

The maintenance cost of the motor-driven station is considerably lower than that of the oil-engine-driven station.

The motor-driven station has several other inherent advantages over the oil-engine-driven stations. One of these results from the fact that the motor-driven station requires but little or no water for its operation; consequently, when station locations are being considered, the supply of water is not a problem. A second advantage is that altitude has a much less effect on the operation of electrical equipment than on internal combustion engines, and thus the altitude of the station is not a hindrance to the motor-driven station.

These two advantages tend toward permitting the lines to be more readily built on the arc of a great circle of the earth at a reduction in the length of the line.

Still another advantage of the motor-driven station is that electrical energy is available for station lighting, and for lighting and other appliances in the homes of the operators without the installation of auxiliary engines and generators.

The motor-driven station also has an advantage in that the number of operators required is only half the number required by the oil-engine station, and this tends to reduce the labor turnover and labor troubles.

Motor-driven Centrifugal Pumps *vs.* Motor-driven Reciprocating Pumps

The question of when to use motor-driven centrifugals and when to use motor-driven reciprocating pumps is one that arises, and again the answer is dependent upon a number of factors.

It is generally conceded, however, that for main line booster work the centrifugal pump has everything in its favor. Its first cost is low, it is easily and quickly installed, and it is very easy to move from one location to another.

It is also generally conceded that the reciprocating or power pump has all of the advantages when the capacity to be pumped is small, usually less than 20,000 bbl. per day, or the viscosity of the oil is high, usually above 400 sec. Universal Saybolt.

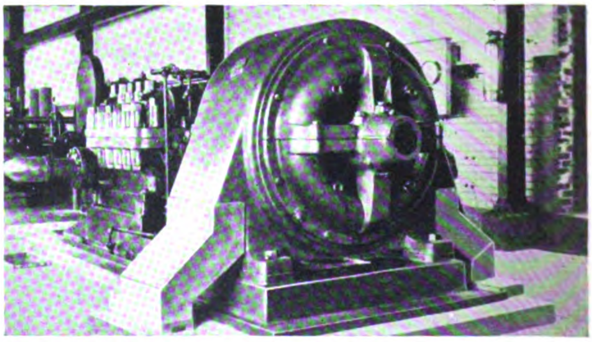

Fig. 4. A 1000-hp. 1800-r.p.m. 2200-volt Squirrel-cage Induction Motor Driving Cameron Oil-pipe-line Pump (Standard Pipe Line Company, Mandeville, Ark.)

When other conditions of pumping are involved, *i.e.*, when the capacity is over 20,000 bbl. and the viscosity is less than 400 sec. Universal Saybolt, there is a question as to what type of pump should be used.

The matter of efficiency is an important one. The manufacturers of power pumps guarantee higher efficiencies for their units than do the centrifugal pump manufacturers. If squirrel-cage motors are used, however, the efficiency of the higher-speed motor used on the centrifugal pump is usually somewhat better than is the efficiency of the low-speed motor used with the reciprocating pump, although if synchronous motors are used the difference in motor efficiencies will be small.

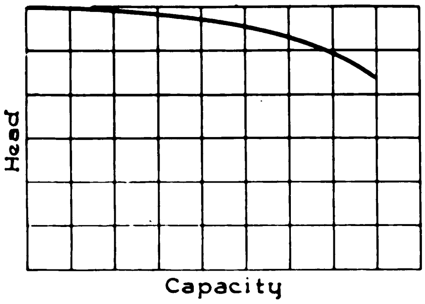

Fig. 5. Typical Head-capacity Curve of a Centrifugal Pump

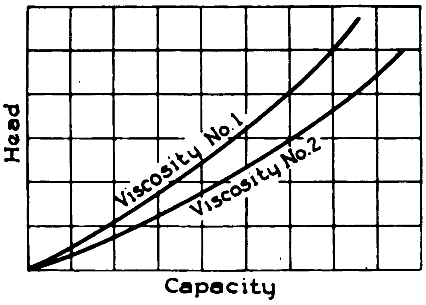

Fig. 6. Typical Head-capacity Curves of Pipe Line with Oil at Different Viscosities

It is also necessary to take into account the losses in mechanical transmission to the reciprocating pump, the first costs, and the question of whether the efficiencies of the pumps are maintained over a long period of time. For any particular problem these matters should be investigated and considered carefully.

The advantages of the centrifugal pumping station are:

(1). First cost is low, and loss due to unsalvable material is low.
(2). The pump house is small and the foundations are also small.
(3). The installation is easily and quickly made.
(4). The unit is comparatively small and light.
(5). Motor is direct connected to pump.
(6). Constant pressure can be readily and efficiently maintained with varying viscosities of oil.
(7). Smaller manifold is required.
(8). This unit lends itself more readily to automatic control.

The disadvantages of the centrifugal unit are:

(1). Lower efficiencies.
(2). Units not available for handling all capacities and oil at all viscosities.

The advantages of the motor-driven reciprocating pumping station are:

(1). High efficiencies.
(2). Can efficiently handle small as well as large capacities.
(3). Has less loss in efficiency when pumping high viscosity oil.
(4). Constant pressure at different oil viscosities readily maintained.

The disadvantages of the reciprocating pump unit are:

(1). High first cost.
(2). Larger buildings and heavier foundations required.
(3). Larger loss in unsalvable equipment.
(4). Longer time for installation required.

Maintaining Constant Pressure with Centrifugal Pumps

One feature of the centrifugal pump which has been referred to as a disadvantage by some pipe line engineers is the fact that the head capacity curve of this type of pump has a drooping characteristic, as shown in Fig. 5, and constant pressure at different capacities cannot be obtained. These engineers say that so long as there is oil to pump, a main line should be operated at its maximum allowable safe pressure, in order to obtain the maximum pumpage throughout the year, regardless of the viscosity of the oil being pumped.

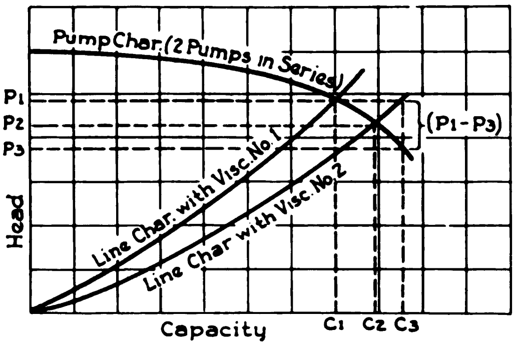

Fig. 7. Superposition of the Characteristic Curves in Figs. 5 and 6

Undoubtedly the ability to maintain constant pressure under different conditions of operation is desirable, and it is possible to secure constant pressure throughout the year with the use of centrifugal pumps and still maintain overall station efficiency in at least two simple ways, *viz.:*

(1). By the use of a single-stage booster pump driven by an adjustable varying speed motor, to be used in series with the main pumps.
(2). By changing pump impellers.

Fig. 6 shows pipe line characteristics for a pipe line with oil at two different viscosities. This difference in viscosity might be due to either a change in temperature of the same oil or to a change in the kind of oil being pumped. In either case the results would be the same.

By superimposing the main pump head-capacity curve on the pipe line characteristics, as shown in Fig. 7, it is evident that when the viscosity drops the

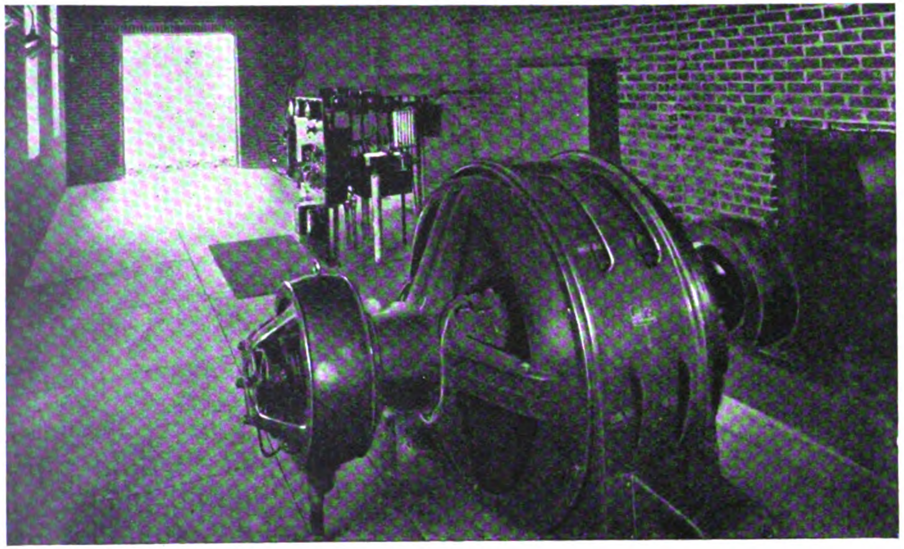

Fig. 8. A 600-hp. 514-r.p.m. Synchronous Motor, with Magnetic Starter, in the Council Hill Station, Okla. (Oklahoma Pipe Line Company)

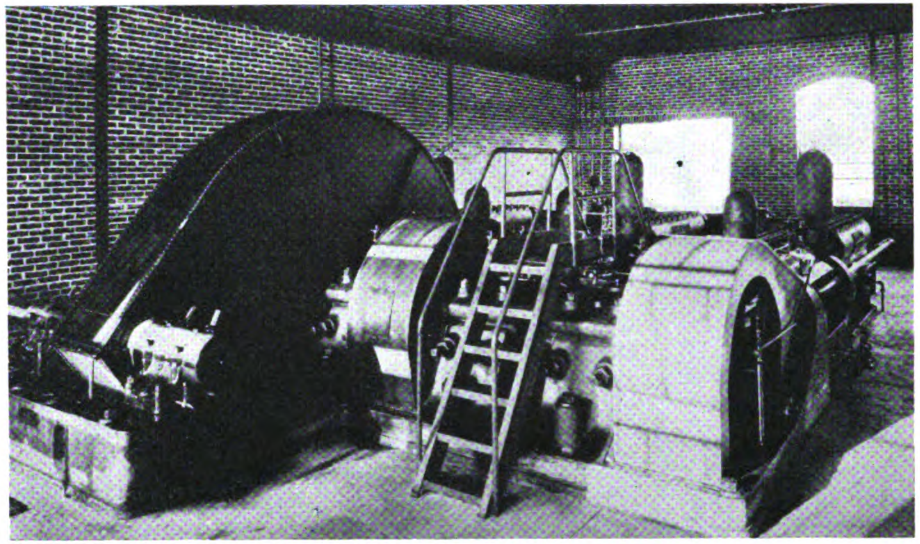

Fig. 9. A Prescott Pump in the Council Hill Station, Driven by the Synchronous Motor Shown in Fig. 8 and Separated from it by a Fire Wall

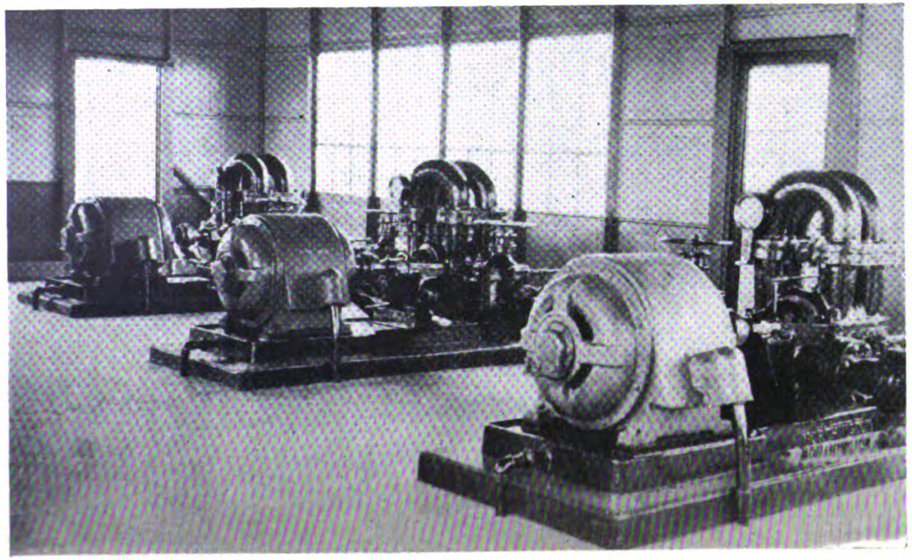

Fig. 10. Three 250-hp. 3600-r.p.m. 2200-volt Induction Motors Driving Worthington Oil-pipe-line Centrifugal Pumps (Bowie, Texas,Station, Magnolia Pipe Line Company)

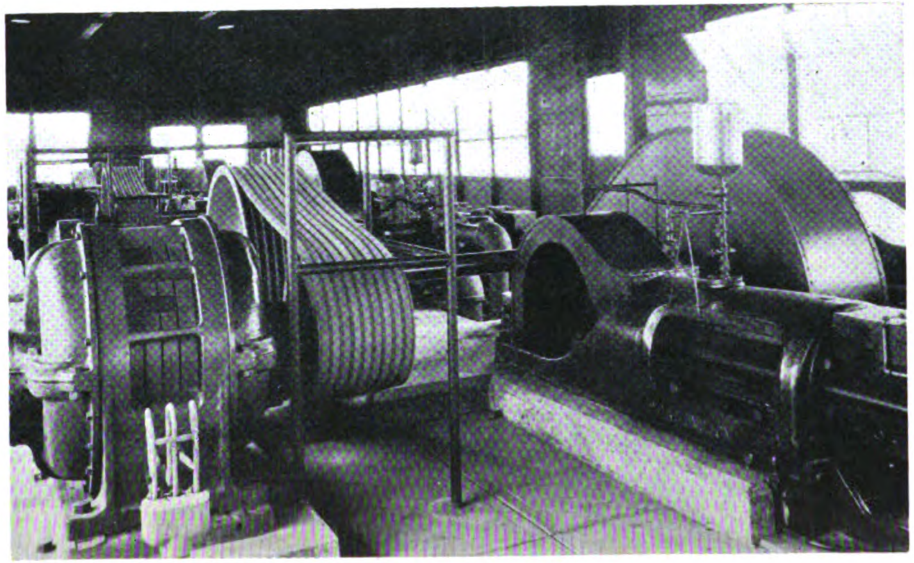

Fig. 11. Three 150-hp. 720-r.p.m. 2200-volt Induction Motors with Hand-starting Compensators and Texrope Drive for Worthington Duplex Oil-pipe-line Pumps (Magnolia Pipe Line Company, Crane, Texas)

capacity will go up, but the pressure will drop. If P_1 is the maximum allowable pressure, it will be required for the highest viscosity oil, and P_2 will be less than P_1 although the capacity C_2 will be greater than the capacity C_1. However, if the pressure P_1 were maintained on the lower viscosity oil, the capacity C_3 would be obtained and this capacity would be greater than either the capacity C_1 or C_2.

Now as the two viscosities chosen are the maximum and minimum that are to be considered, a booster pump capable of handling full capacity with a maximum head of P_1 less P_3 will be satisfactory. Since the pressure of a centrifugal pump varies as the square of the speed, it is evident that, if an adjustable varying-speed motor is used, any oil with viscosities between the maximum and minimum values to be handled by a line can be handled at any pressure less than P_1 minus P_3, but this pressure will always be sufficient to maintain station pressure at P_1.

On a certain 50,000 bbl. per day pipe line, and with certain main centrifugal pumps, it was found that P_1 minus P_2 was about 70 lb. and P_1 minus P_3 was about 75 lb. A single-stage booster pump was installed to handle full capacity at 75 lb. pressure. This pump required a 75-hp. motor. The two main motors were of 400 hp. each and the load on them was approximately 360 hp. each, so that the total station load was approximately 795 hp. with summer viscosity and the two main units with the booster unit running.

In the winter the booster pump is to be shut down entirely, but during the fall and spring it is to be run at such a speed as will give the required boosting pressure, even though this be as low as 10 to 15 lb. At a pressure of about 15 lb., this pump will require about 19 b.hp. The overall motor efficiency, running at low speed, and including resistor losses, would be about 58 per cent which would mean that approximately 14 hp. would be lost in the motor and resistor. The total station load under these conditions will be approximately 750 hp. From this it is evident that the 14 hp. loss in the 75-hp. motor and resistor would only affect the overall station efficiency about 1¾ per cent. The booster pump efficiency at this low head is about 60 per cent and therefore an additional loss of 7½ hp. will occur in the pump so the total effect on the overall station efficiency is only about 2¾ per cent.

The efficiency of the booster unit, when running at full speed, which will be during the summer months, is about the same as the efficiency of the main units; consequently maximum efficiency is obtained. When the booster unit is running at reduced speeds, the efficiency of the station is somewhat less than the maximum efficiency, but the booster pump never reduces the station efficiency more than about 2¾ per cent.

The slip-ring motor used is equipped with collector rings mounted in an enclosure which is designed in accordance with the requirements of the U. S. Bureau of Mines for operation in an explosive gaseous atmosphere, and consequently this motor is comparable with the ordinary squirrel-cage motor of the type being used to drive the main pumps.

The control for this motor is mounted in a separate control room with the remainder of the electrical control equipment and the speed of the motor is easily controlled by the operator who can watch the station discharge pressure gauge and can adjust the speed of the motor so that constant pressure can be maintained at all times.

Since the viscosity of the oil will remain constant for comparatively long periods of time, it will not be necessary for the operator to change the speed of the booster pump motor frequently even though he can readily do this. This feature could be made automatic with the line pressure as the controlling factor, if this were desirable.

From the foregoing it is evident that constant pressure can be economically and conveniently maintained by this method throughout the year, regardless of the viscosity of the oil.

Another point worthy of consideration is the flexibility which this method of pressure control allows the designer of the pipe line. A station may be found not to be located at exactly the proper point on the line because of some error made in the assumptions of viscosity, and then this flexibility will take care of the situation.

The cost of such booster equipment, including motor, control, pump, and installation, would not increase the station cost more than $3500 or approximately 6 to 7 per cent of total station cost.

The method of changing impellers would not be so convenient or flexible as the foregoing method, nor would the correct pressures be obtained at all times. An approximation can be reached in this way, however, at a comparatively low cost.

Frequently three centrifugal units are installed, two of which operate in series and the third as a spare. It would be possible to have different impellers in each pump. Then, by operating various combinations, different pressures and capacities could be obtained. With one change of impellers in addition to this, a fairly flexible arrangement could be obtained. However, the first cost of the extra set of three impellers, one for each pump, would be about 50 per cent of the installed cost of the booster pump. Considering the cost of changing impellers at least twice a year, the booster proposition seems the better of the two when one considers the additional flexibility and convenience of operation it affords.

There are other methods of obtaining the same results, *viz.:*

(1). By the use of slip-ring, adjustable varying-speed motors on the main pumps.

(2). By the use of slip-ring motors with pump-back or Scherbius control method.

The first of these would be convenient but not very efficient, and the second method involves equipment which would be expensive and complicated for the purpose.

Automatic Control

The problem of automatic control of a motor-driven centrifugal pump station has several angles.

If there is a surge tank at each station, it would be relatively simple to automatically control the motors in such stations. If there is no tank, the arrangement of control for automatic operation is also quite simple, provided the station is preceded by another centrifugal pump station. If there is no tank, and if the preceding station is a reciprocating pump station, the problem is more difficult because of pressure variations or pulsations due to the reciprocating pumps.

The advantage of having an automatically operated station is the reduction of labor made possible thereby. However, at the present stage of development, there should be at least one operator available at or near the station at all times.

Full automatic control of electric railway substations and water power generating stations has been accomplished and is in quite common use today. The problems involved in such automatic control are far more complicated than the problems involved in the automatic control of oil pipe line pumping stations where centrifugal pumps are used, and there is no reason why, with careful application and study, a complete line could not be operated entirely automatically under supervision of a dispatcher and with trained inspectors stationed at strategical locations along the line.

Up to the present time, the only attempts at making stations automatically controlled have been by using the pressure in the pipe line as the controlling factor. Arrangements have been made to shut stations down on loss of suction pressure, and also for shutting down the station on loss of discharge pressure which latter would indicate a line break on the discharge side of the station. Provisions have also been made to automatically shut down stations on high discharge pressures which would be caused by operating against a closed valve. Attempts have been made to automatically start and stop the station under operating conditions, by using the suction pressure as the controlling factor.

Conclusions

The fact that there is already installed in main oil pipe line pumping stations over 115,000 hp. in electric motors shows that the pipe line operators have investigated and accepted the electric motor as an economical device for driving main line oil pipe line pumps. This same fact shows that the power companies are in a position to render a highly efficient service for this application.

The motor-driven station, whether the centrifugal or the reciprocating pump is used, has decided advantages due to:

(1). Low first cost.
(2). Small loss in non-salvable material.
(3). Less labor required.
(4). Shorter time of installation.
(5). Electric power available for lighting and other conveniences without requiring installation of generators at pump station.
(6). Characteristics of country through which the line must pass, such as quantity of water available and altitude, have less effect on station location and consequently the line can be more nearly built on the arc of a great circle of the earth.
(7). Fewer auxiliaries required.
(8). Simpler manifold needed.

The motor-driven station, particularly when the centrifugal pump is used, will readily allow full automatic control and it is to be expected that tendencies in the future will be more and more toward this method of operation.

Use of Motors Increasing on the Farm

A marked increase in the use of electric motors by the farmer is indicated by statistics. Figures compiled by an electrical manufacturing company show that during 1928 twice as many of its portable farm chore motors were purchased as were installed in the previous year.

The figures indicate that the single-phase motor is the more popular, outnumbering the three-phase 24 times. The most popular rating was the five-horsepower size, the seven and one-half horse-power motor being next and the three-horsepower, last. Geographically, the middle-west district with Chicago as its center used the largest number of motors, the next largest users being the west coast, the district with Philadelphia as a nucleus, and the Rocky Mountain section.

According to the manufacturer, many improvements have been made in the design of these units. These include the relocation of the starting box to give better operation, a new location of the wheels, and an increase in the face of the pulley to allow for the use of larger belts.

The Testing of Transformers

PART I: RESISTANCE; POLARITY; PHASE ROTATION; AND RATIO

By G. CAMILLI
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The general subject of transformer testing extends, with overlapping ranges, from research investigations through factory production testing to occasional but at times essential tests after installation. When we solicited this serial we asked the author to include only such tests as the operating engineer might be called upon to make, and to describe how they can be conducted without elaborate equipment. When completed, the serial will thus form an instructive manual for which there has been great need.—EDITOR

THE rapid growth of power systems has been paralleled, in fact, has been made possible, by the development of power units of increasingly large size and capable of performing under operating conditions that have become more severe and complex. Also, every few years the hitherto maximum voltage usable in commercial practice has been raised to a higher value, and these advances have exerted a similar progressive influence upon the selection of the sub-voltages. These factors in the evolution of the modern power system have brought about marked changes in most of the equipment involved. Of the power units, transformers have had to respond to all the new requirements—greater capacity, higher voltage, strenuous duty, and intricate performance. As the result we today have some transformers of 80,000 kv-a. and others of 220,000 volts, transformers built to withstand not only the exacting demands of the load but also the unavoidable stresses of line short circuits and lightning discharges, and units that are no longer inflexible in ratio while under load.

The design, application, and operation of transformers have thus become of a new order, and in consequence the matter of testing has assumed an increased importance. To assist the user in becoming familiar with the details of up-to-date commercial testing practice, the writer has prepared this serial in collaboration with a number of other engineers who are versed in the subject. (1)

Tests

The following are general tests on transformers:

(*a*). Resistance, cold and hot
(*b*). Polarity and Phase Rotation
(*c*). Ratio
(*d*). Core or No-load Loss and Exciting Current
(*e*). Copper or Load Loss, and Impedance Voltage
(*f*). Full-load Heat Run
(*g*). High-potential Test
(*h*). Induced-voltage Test.

Sequence of the Tests

The cold resistance of the windings must obviously be taken before the transformer has been heated by any other test. The polarity and phase rotation, ratio, core loss and exciting current, copper or load loss, and impedance voltage tests should be made next, their sequence being left largely to the man making them. The full-load heat run, high-potential test, and induced-voltage test should be made last and in the order named.

RESISTANCE MEASUREMENTS

The resistance measurements are used for two purposes: for calculating the I^2R loss; and for determining the temperature of the windings at the end of the heat run. Several methods are in use for making these resistance measurements. The direct methods make use of such instruments as the Wheatstone bridge, the Thomson bridge (sometimes called "double bridge"), or their equivalents. The indirect method or "drop of potential method" is the recommended one and should be employed unless the rated current of the transformer winding is less than one ampere, in which case the Wheatstone bridge method may be used.

For the drop of potential method, direct-current ammeters and voltmeters of suitable range are required, simultaneous readings being taken on each. If the potential drop is less than one volt, a potentiometer should be used in place of the voltmeter. From these readings the resistance is calculated by Ohm's law:

$$R=\frac{E}{I}$$

The connections for measuring transformer resistance by this method are shown in Fig. 1, wherein the resistance of the high-voltage winding is being determined. The voltmeter leads should be attached to the terminals of the transformer in order to avoid including in the readings the voltage drop in the temporary connections.

Instruments of such capacity should be chosen that the deflections obtained are reasonably large in order to reduce the error of observation. Direct current should of course be employed and should be of sufficient amount to give a good deflection on the ammeter. However, the current should not be more than 15 per cent of the rated current of the winding because a larger value may heat the winding appreciably and thus cause the resistance determinations to be inaccurate.

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(1) The author is indebted to F. I. Manvel, Transformer Field Engineer, for his helpful suggestions and criticisms, and also to other engineers who have read the proof.

Particular care should be taken when making the cold resistance test because this combination of temperature and resistance is the basis for the later calculations made of temperature rise at the end of the heat run. The temperature at the time of making the cold resistance measurement may be safely assumed to be the same as that of the transformer oil if this oil temperature has remained constant during several preceding hours while the transformer has remained idle.

However, whether they will appear in the same direction as viewed from the terminals depends on the relative directions of the windings. Thus, in Fig. 2, voltages H_1, H_2 and X_1 X_2 are in the same direction; while in Fig. 3, they are in opposite directions.

Since the relative direction of the induced voltages as they appear at the terminals of the windings is dependent on the order in which these terminals are taken, it is necessary that the designation "polarity" in order to have any certain meaning must be referred to a perfectly definite order in which the terminals shall be considered. By common usage, polarity refers to the voltage vector relations of the transformer leads as brought outside the case with both high-voltage and low-voltage leads being taken in the same order (from left to right or right to left) facing the same side of the transformer in both cases.

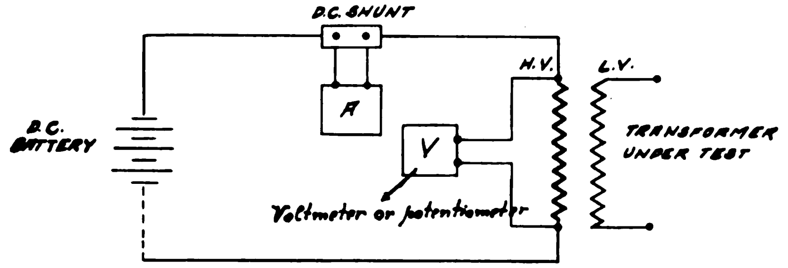


Fig. 1. Drop-of-potential Method of Connections for Making Either Cold or Hot-resistance Measurements of Transformer Windings; Here Applied to the High-voltage Winding

POLARITY AND PHASE ROTATION

Polarity and phase rotation are of interest primarily on account of their bearing on the banking and parallel operation of transformers. Consequently if any doubt should exist regarding the correctness of the polarity markings of a power transformer, a check should be made.

In the past, considerable confusion existed because transformers of similar rating when built by different manufacturers did not have like polarity; but a uniform practice in transformer polarity has since been adopted by the N. E. M. A., as follows:

All power transformers................Subtractive polarity
  Except distribution transformers 200
    kv-a. and below with voltage ratings
    7500 volts and below.............Additive polarity.

Before proceeding to illustrate the methods used to test polarity, a brief digression into its origin in the transformer may prove useful.

When arranging transformers for parallel operation, attention need be given only to the vector relations of voltage because those of current do not determine either polarity or phase rotation.

In analyzing the voltage relations, the most logical procedure is to consider only the *induced voltages*.

Since the primary and secondary induced voltages are generated by the same flux, they must be in the same direction in each turn regardless of the manner in which the primary and secondary coils are wound.

Thus referring to the sketch in Fig. 2, polarity is the relative direction of induced voltages from H_1 to H_2 as compared with that from X_1 to X_2, both being viewed in the same order (from left to right, facing the low-voltage side).

Additive and Subtractive Polarity

When the induced voltages of the high-voltage and low-voltage sides are in opposite directions, as in the sketch in Fig. 3, the polarity is said to be *additive*; and when the induced voltages are in the same direction, as in Fig. 2, the polarity is said to be *subtractive*. The reason for this nomenclature will be evident from the following: Referring to the tank sketch in Fig. 2, if a high-voltage lead be connected to the adjacent low-voltage lead, for instance H_2 to X_2, and the transformer be excited from either side, the voltage across the remaining leads H_1 to X_1 will be the difference of the voltages of the two sides. Following the voltage from X_1 through X_2 to H_2 and then to H_1 it is evident that the voltage H_2 to H_1 will oppose the voltage X_1 to X_2. Hence, the polarity is subtractive.

Referring now to the tank sketch in Fig. 3, which shows the primary and secondary induced voltages to be in opposite directions, if an H lead be connected to the adjacent X lead, for instance H_1 to X_2, and the transformer be excited, the voltage across the other leads, H_2 to X_1 will be the sum of the primary and secondary voltages, as can be deduced from the explanation given in the previous paragraph. Hence, the polarity in this latter case is additive.

In Fig. 4 are shown the standard markings for the leads of single-phase transformers of additive polarity and also those of subtractive polarity.

Testing of Polarity

The three following methods are commonly employed for testing the polarity of transformers, and the method which is most convenient for a particular case should be chosen.

(1). When a standard transformer of the same rated ratio as the one under test is available, the polarity and ratio tests may be combined.

The high-voltage winding of the transformer under test should be connected directly in multiple with the high-voltage winding of the standard transformer, and the low-voltage winding of the transformer under test should be connected in series with the low-voltage winding of the standard transformer through a voltmeter to indicate any difference in voltage. With these connections, the high-voltage winding should be excited at reduced voltage, and if there is no difference in voltage indicated by the voltmeter the polarity and ratio of the two transformers are identical.

If a small difference of voltage is indicated by the voltmeter, the polarity is correct but the ratio is not. If the difference in voltage is greater than that across the low-voltage winding of one of these transformers, the polarity is probably reversed and further tests should be made to determine whether this is true.

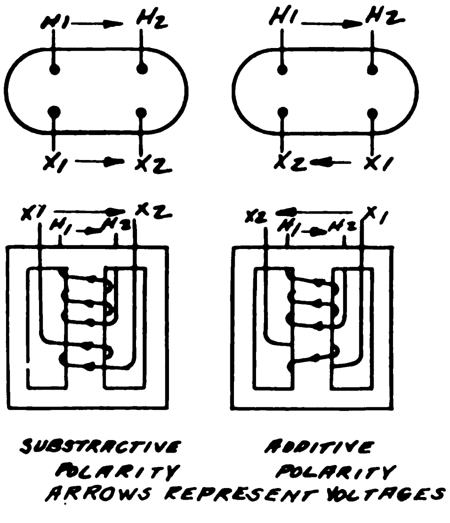

H1 → H2
H1 → H2
X1 → X2
X2 ← X1
X1 → X2
H1 → H2
X2 ← X1
H1 → H2
SUBSTRACTIVE POLARITY
ADDITIVE POLARITY
ARROWS REPRESENT VOLTAGES

Fig. 2 Fig. 3

Figs. 2 and 3. Tank, Core, and Windings of Two Transformers of Unlike Polarity

(2). The polarity may be determined at the same time as the resistance by making use of direct current as follows:

With direct current passing through one winding, usually the high-voltage, connect a high-voltage voltmeter across the terminals of this excited winding so as to obtain a small positive deflection. Then transfer the two voltmeter leads directly across the transformer, *i.e.*, the lead from the right-hand high-voltage terminal being placed on the right-hand low-voltage terminal (facing the high-voltage side), and the lead from the left-hand high-voltage being placed on the left-hand low-voltage terminal. The direct-current excitation is then broken and the inductive kick in the voltmeter observed. If the needle swings in the *same* direction as before, the polarity is *additive*, otherwise it is subtractive.

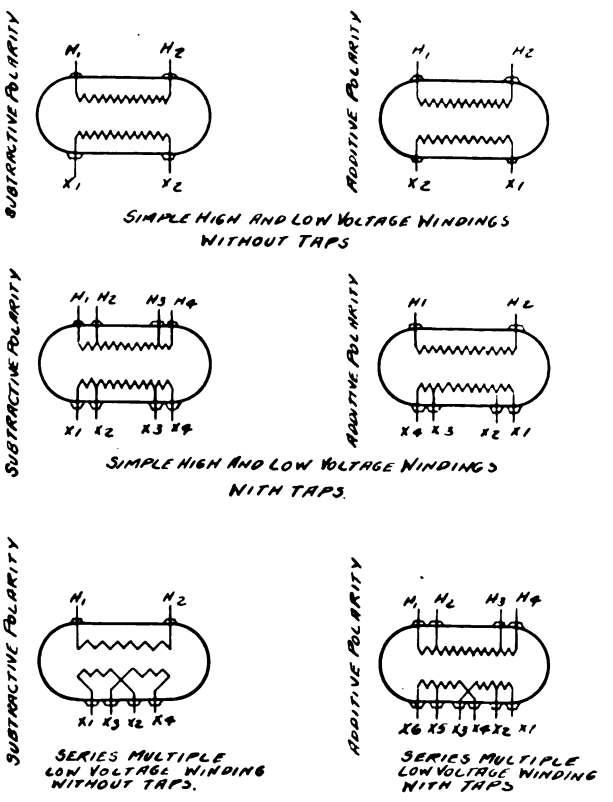

SUBTRACTIVE POLARITY
H1 H2
X1 X2
ADDITIVE POLARITY
H1 H2
X2 X1
SIMPLE HIGH AND LOW VOLTAGE WINDINGS WITHOUT TAPS
SUBTRACTIVE POLARITY
H1 H2 H3 H4
X1 X2 X3 X4
ADDITIVE POLARITY
H1 H2
X4 X3 X2 X1
SIMPLE HIGH AND LOW VOLTAGE WINDINGS WITH TAPS
SUBTRACTIVE POLARITY
H1 H2
X1 X3 X2 X4
SERIES MULTIPLE LOW VOLTAGE WINDING WITHOUT TAPS
ADDITIVE POLARITY
H1 H2 H3 H4
X6 X5 X3 X4 X2 X1
SERIES MULTIPLE LOW VOLTAGE WINDING WITH TAPS

Fig. 4. Standard Polarity Markings for the Leads of Single-phase Transformers

(3). If neither a standard transformer nor a source of direct current is available, the polarity may be determined as follows:

With the primary and secondary in series, one primary lead being connected to the adjacent secondary lead (such as H_2 and X_2 in Fig. 2), the transformer is excited from an alternating-current source on either side and the voltages across the high-voltage winding and also that between the free primary and secondary terminals are measured. If the latter voltage is found to be *less* than that across the high-voltage winding, the polarity if *subtractive;* if more, the polarity is additive.

The polarity test may be satisfactorily made in this manner if the ratio of primary to secondary voltages is low: *e.g.*, with a transformer rated 110,000/66,000 volts. Thus, referring to Fig. 5, with the application of low alternating voltage, say 110 volts across H_1 and H_2, the difference between $110-66$ and $110+66$ volts will be easily discernible on the scale of a 150-volt meter. If, however, the transformer were rated at say 110,000/110 volts, such as a standard potential transformer, it is obvious that with the same connections and applications of 110 volts to the H_1 and H_2 terminals the difference of $110-0.1$ and $110+0.1$ will not be so readily apparent on the scale of a meter. Under these conditions, the polarity should be checked by the direct-current method already described.

Three-phase Transformers

In single-phase transformers, the primary and secondary voltages are either in phase or in opposition, and this is completely specified by the polarity or the lettering of the leads.

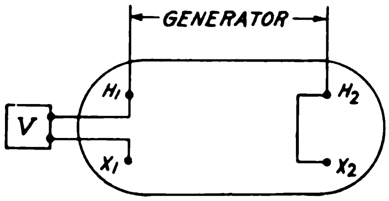


Fig. 5. Polarity-checking Connections for a Transformer the Primary and Secondary Voltages of which Are Greatly Different

In polyphase units, however, these vector relations are more complicated and are represented by voltage diagrams because the mere lettering of the leads does not indicate the relations completely. Furthermore, polarity alone is inadequate to represent the vector relations in polyphase connections as the angular phase relation between the high and low-voltage windings is also involved. The phase relation is called "Angular Displacement" and is defined in the A. I. E. E. Standardization Rules as the angle between the lines H_1—N and X_1—N (N being the neutral point of the diagram). The location of the H_1 lead for single-phase units is defined as being on the right-hand side when the observer is facing the high-voltage side. The location of the X_1 lead is fixed so as to make the diagram fall under one of the standardized groups (Figs. 8 and 9) to be described later. Under these conditions, the angular displacement in Fig. 6(b) is zero and that in Fig. 7(b) is 180 deg.

To Obtain Voltage Diagrams by Test

If desired, the voltage diagrams can be determined by the following method which neglects the polarity and phase-rotation tests. Connect one of the high-voltage leads to one of the low-voltage leads, excite the transformer at a voltage that is safe for the low-voltage circuit, measure the voltages between all the other high and low-voltage leads, and plot them to scale. For instance, referring to Fig 6(a), if H_3 be connected to X_3 and the voltages measured, a diagram like that in Fig. 6(c) would be obtained; or referring to Fig. 7(a) a connection from H_3 to X_3 would result in a diagram like that in Fig. 7(c).

If this test were applied to Y-Y-connected units of the same polarity the same diagrams as in Figs. 6(c) and 7(c) would be obtained. Thus, such a test will not determine whether the internal connection is delta-delta or Y-Y. However so far as parallel operation is concerned, the distinction is unnecessary. The test will indicate the "angular displacement" between the high and low-voltage circuits but cannot distinguish between connections that belong to the same group, *i.e.*, between the connections of windings that can be paralleled with each other.

It will be evident that obtaining voltage diagrams by such measurements becomes difficult when the voltage rating of one side is very small compared to that of the other.

If the voltage diagrams of transformers which are to operate in parallel are available, it is then only necessary that these diagrams coincide and the corresponding terminals can be connected together.

It is entirely unnecessary then to question the polarity and phase rotation, because when the voltage diagrams coincide the leads which are to be connected together will have the same potential, this being the basic requirement for parallel operation whereas tests of polarity, phase rotation, etc., merely furnish the means to arrive at this condition. When voltage diagrams coincide, polarities and phase rotations must necessarily agree, although the converse is not necessarily true.

Phase Rotation

In addition to the polarity tests, sometimes it is necessary to check the phase-rotation of three-phase and six-phase transformers.

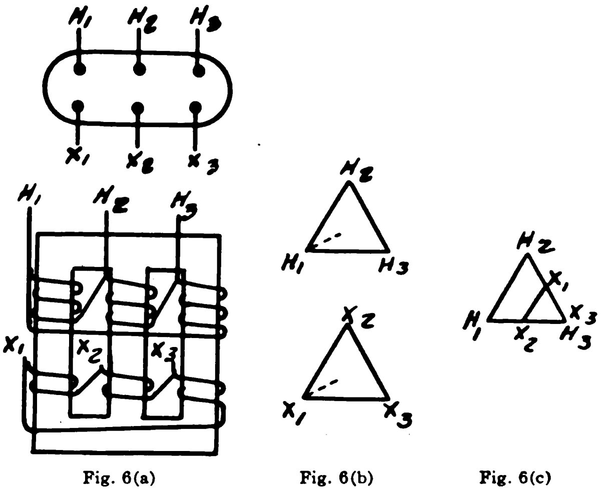


Fig. 6(a) Fig. 6(b) Fig. 6(c)

Fig. 6. Three-phase Transformer, Angular-displacement Diagram (Displacement Zero), and Voltage-vector Diagram

The phase-rotation meter (a small three-phase induction motor may be used) should be connected to the *high-voltage* side of the transformer, and a relatively low voltage applied to the high-voltage side. This voltage should be only sufficient to cause the meter to rotate, and the direction of rotation should be noted. Then the leads from the meter should be transferred straight across the transformer to the low-voltage terminals. The transformer again should be excited from the high-voltage side with voltage sufficient to cause the meter to rotate, and the direction of rotation noted. The phase rotation of the transformer is standard if the meter revolves in the same direction as before. In three-phase transformers which have been marked according to the A. I. E. E. Rules, phase rotation is the same in the sequence X_1 X_2 X_3 as in H_1 H_2 H_3, and therefore a check may be made by transferring the leads of the phase-rotation meter from H_1 to X_1, from H_2 to X_2, and from H_3 to X_3.

In three-phase six-phase transformers which do not have a permanent neutral, the coils should be connected in a three-phase connection, and phase rotation taken as described for three-phase transformers. If the neutral connection is permanently made, the phase rotation should be taken by shifting the lines from H_1 H_2 H_3 to X_1 X_3X_5 respectively, then to $X_2X_4X_6$ respectively. The rotation should be the same in each case.

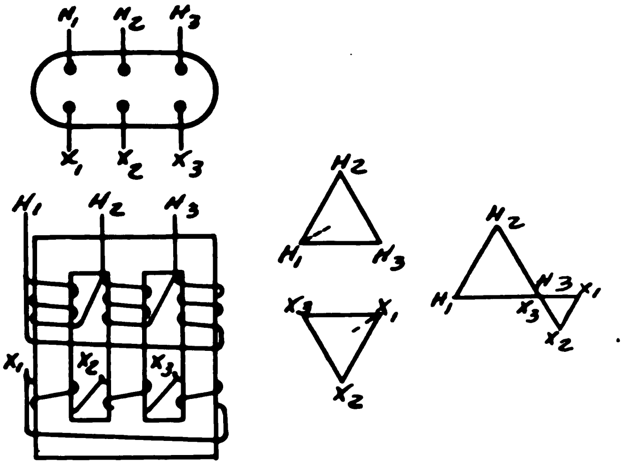

H1
H2
H3
X1
X2
X3
H1
H2
H3
X1
X2
X3
H2
H1
H3
X3
X1
X2
H2
H1
H3
X1
X3
X2

Fig. 7(a) Fig. 7(b) Fig. 7(c)

Fig. 7. Three-phase Transformer, Angular-displacement Diagram (Displacement 180 Deg.), and Voltage-vector Diagram

Three-phase Transformer Groups

Three-phase transformers utilizing the common connections may be divided into three groups based on their angular displacements, as shown in Fig. 8.

Four of the normal three-phase to six-phase diagrams are shown as Groups 4 and 5 in Fig. 9.

To operate in parallel, transformers must belong to the same group. No interchange of external leads can change one group into another. Thus, two delta-delta transformers, one of Group 1 and the other of Group 2, cannot be operated in parallel. If the high-voltage diagrams be superposed, the low-voltage diagrams will not coincide. All Y-delta or delta-Y transformers, however, can be reduced to the same diagrams, and therefore they are classed in only one group.

RATIO

The ratio of a transformer is the numerical relation between the no-load primary and secondary voltages.

In large power transformers, due to their comparatively small number of turns, this test does not offer any special difficulties. Great care, however, must be used in order to obtain the correct ratio of small high-voltage transformers.

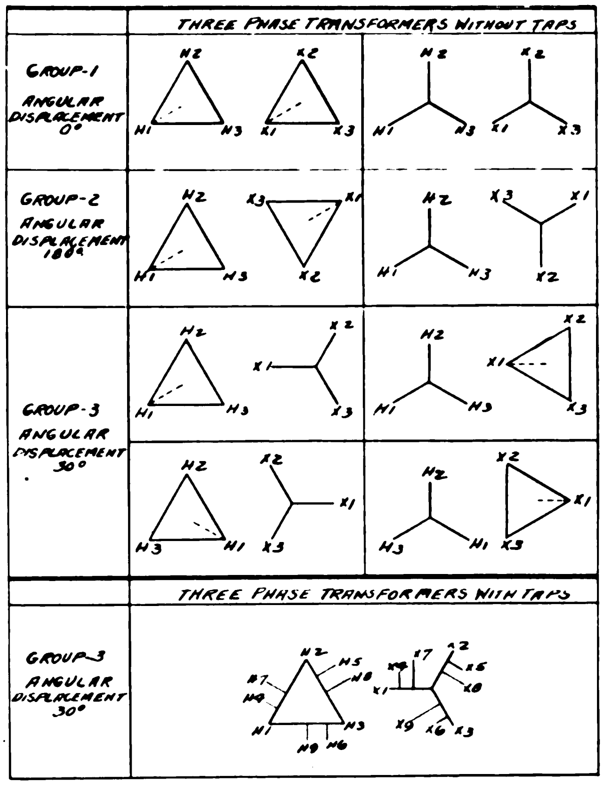

THREE PHASE TRANSFORMERS WITHOUT TAPS
GROUP-1
ANGULAR DISPLACEMENT 0°
GROUP-2
ANGULAR DISPLACEMENT 180°
GROUP-3
ANGULAR DISPLACEMENT 30°
THREE PHASE TRANSFORMERS WITH TAPS
GROUP-3
ANGULAR DISPLACEMENT 30°
H1
H2
H3
X1
X2
X3

Fig. 8. Group Classification of the Polarity, or Lead Markings, and the Voltage-vector Diagrams for the Usual Three-phase Transformer Connections

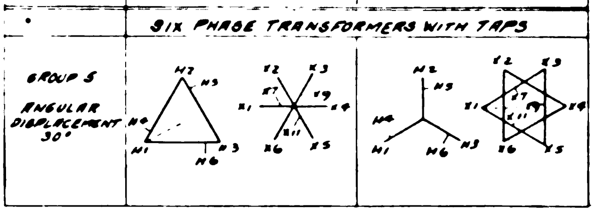

SIX PHASE TRANSFORMERS WITHOUT TAPS
GROUP 4
ANGULAR DISPLACEMENT 0°
GROUP 5
ANGULAR DISPLACEMENT 30°
SIX PHASE TRANSFORMERS WITH TAPS
GROUP 5
ANGULAR DISPLACEMENT 30°
H1
H2
H3
X1
X2
X3
X4
X5
X6

Fig. 9. Group Classification of the Polarity, or Lead Markings, and the Voltage-vector Diagrams for the Usual Six-phase Transformer Connections

During the ratio test the transformer should be operated at normal frequency or higher, and at normal voltage or lower. An abnormally low frequency or high voltage would tend to make the core density and exciting current abnormally large. Such a high voltage would also place an unnecessary strain on the insulation. Transformers having capacities of 500 watts or less and having an exciting current of more than 10 per cent should be tested only at normal voltage and frequency. For other transformers, 10 per cent of the rated voltage of the winding is the lower limit at which ratio should be measured.

Test Methods

The common methods of measuring voltage ratio are:

(1). Voltmeter Method
(2). Standard Transformer Method
(3). Resistance Balance Method.

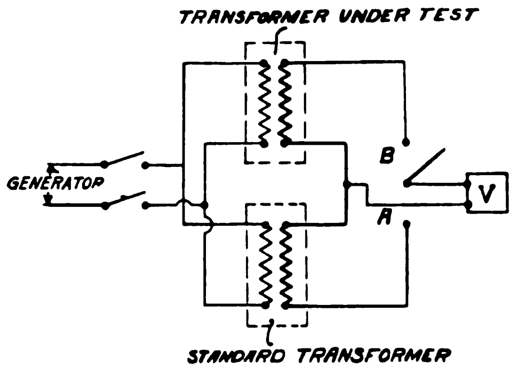


Fig. 10. Connections for Determining the Ratio of a Transformer by Comparison with a Transformer of Known Ratio

(1). Ratio by Voltmeter Method

This method is the one usually employed for power transformers. In using it, approximately rated frequency should be applied. Two voltmeters are used (with potential transformers if necessary), one to read the voltage of the high-voltage winding and the other to read the voltage of the low-voltage winding.

Holding say, 90, 100 and 110 per cent voltage successively on the voltmeter that is connected to the winding to which potential is applied, simultaneous readings should be taken of the voltage induced in the other winding. Then the meters should be interchanged and the readings repeated, holding the same voltages on the same winding as before.

The ratio of the average of the six high-voltage readings to the average of the six low-voltage readings should check the nameplate ratio within one per cent. If the error is more than one per cent, the ratio should be rechecked with different meters.

It is essential that such potential transformer ratios be chosen as will render the readings of the two meters approximately the same, otherwise the meter errors will not compensate and it will be necessary to apply meter corrections.

If the transformer has ratio adjusters, ratio measurements should be taken (as previously explained) on the full-winding position. On each of the other positions of the adjusters, two sets of readings should be taken—one set with the meters interchanged.

If the transformer does not have ratio adjusters but has taps brought to a terminal board, the same method should be used to determine each tap ratio.

For three-phase transformers the ratio test should be applied to all three phases as explained for single-phase transformers, with the exception that the six readings called for on the full winding of single-phase transformers need be taken on only one phase of the transformer. On the other phases, one set of readings, and another with the meters interchanged, are all that are required.

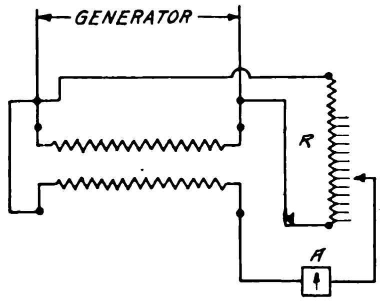


Fig. 11. Resistance-balance Method of Connections for Ratio Test by Current Measurement

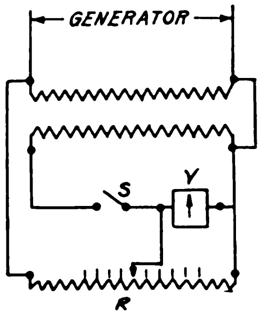


Fig. 12. Another Scheme of Resistance-balance Connections for Ratio Test. This arrangement calls for voltage measurements

When each phase of a transformer is independent and accessible, single-phase power may be used, but it is preferable to employ three-phase power. In all other cases, three-phase power must be used.

Transformers that have Y-diametric connections but do not have the neutral of the Y brought out are tested for ratio with three-phase power. Any inequality in the magnetizing characteristics of the three phases will then result in a distortion of the neutral thereby causing unequal phase voltage. When such inequality is found, the diametric connection should be changed to a Y connection and the phase voltages measured. If these are found to be equal and of proper value (1.73 times the diametric voltages) the ratio is correct.

(2). *Ratio by the Standard Transformer Method*

When measuring the ratio of distribution transformers by voltmeters in the ordinary way, it is necessary to apply practically normal voltage in order to secure accurate results. If only a small percentage of normal voltage be used, the drop due to the load of the measuring instrument may introduce an appreciable error.

The most satisfactory way of measuring the ratio of such a transformer is by paralleling it with another transformer which is of known ratio and which has been specially designed with a large number of taps covering a wide range with very small steps. This latter transformer is used as the standard of comparison.

The test connections are shown in Fig. 10. The primaries being connected in multiple, the secondary voltage across the standard transformer and that across the transformer under test may be read, in turn, by throwing the voltmeter switch down to *A* and then up to *B*. The reading of the voltmeter with the switch at *A*, multiplied by the ratio of the standard transformer, is the impressed voltage on the primary of the transformer under test. From this value, and the reading of the voltmeter with the switch at *B*, the ratio of the transformer under test can be readily determined.

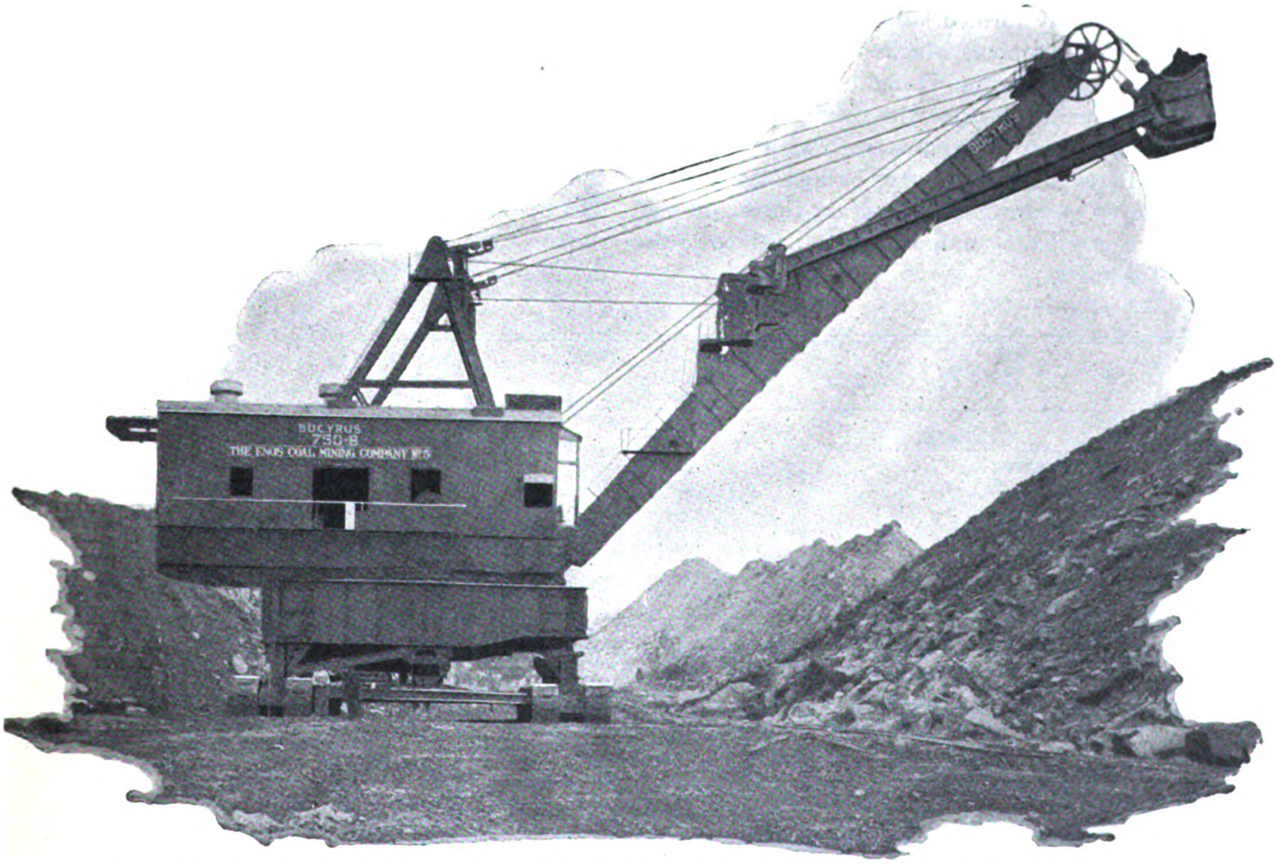
(3). *Ratio by the Resistance-balance Method*

When great accuracy is required, a scheme as shown in Figs. 11 and 12 may be used. In both diagrams, a non-inductive resistance *R* is connected across the high-tension winding. Different taps are located on the resistance so that a zero reading may be obtained on the ammeter *A* (in Fig. 11) and an unchanged reading (when the switch *S* is either open or closed) on the voltmeter *V* in Fig. 12. The ratio of the transformer is then equal to the ratio of the total resistance *R* to that portion of it which is paralleled by the secondary winding, when the foregoing balance is obtained.

Although this method of obtaining ratio gives high accuracy, this exactness is not ordinarily necessary in testing power transformers.

(To be continued)

A Large Electric Shovel



Some of the reasons for the rapidly growing use of electricity for shovel operation are: Reduction in man-hours, in power costs, and in maintenance expense; superior flexibility, higher speed, and greater simplicity of control

The Electrification of the Mexican Railway

PART II

By J. B. COX

Transportation Engineering Department, General Electric Company

Electrification

IN November, 1921, a study of the mountain division was begun for the purpose of determining the results that might be expected from the electrification of this congested district. About two months were spent in looking over the line and equipment, studying the conditions and securing operating data and costs. An equal time was required to analyze these data, estimate the cost of electrification, the savings in operating expenses that would result, and to prepare a report which was submitted in April, 1922.

The unsettled conditions that had existed in the country for the preceding ten years, and the taking over of the railroad by the government from 1915 to 1920, rendered the records for any of this entire period unsuitable for forming a basis for the usual method of estimating the traffic that might reasonably be expected over the line for the following years.

Operating expenses had also been vitally affected during the interval by substantial increases in wages as well as by unusually expensive working agreements insisted on by newly formed labor organizations.

The semiannual reports of the Mexican Railway for the six months ending December 31, 1920 (the first period of operation after the return of the property by the government) compared with a similar period of 1913 (the last six months of operation by the owners prior to government operation for which the records were available) indicates increased costs as shown in Table II.

The comparative costs of the items that would be most directly affected by electrification for the same period are given in Table III.

An analysis of the comparative costs indicated that the motive power in use on the system should receive careful consideration.

The management of the railway suggested that the months of September and October, 1921, should be taken as a basis for the study, since the traffic conditions and operating costs during that period were more representative of anticipated future conditions than any other period for which records were available.

The mountain district constituting the line between Orizaba and Esperanza, a distance of 29.5 miles, was then operated as a separate district, and accurate operating expenses and statistics for steam operation were readily available for comparison with corresponding estimated costs of electrical operation.

The line between Orizaba and Paso del Macho was also included in the original study, but since this was operated with the remainder of the line on into Vera Cruz, and the result of electrification could not be so definitely determined until an exact schedule of operation had been decided on, only an approximate estimate was made for this section.

Of the 29.5 miles between Orizaba and Esperanza, the 19 miles between Encinar and Boca del Monte, which had been given such careful consideration in the original survey, again became the determining factor relative to motive power.

TABLE II

	1913	1920	INCREASE	
			Amount	Ratio
Maintenance of way and structures	$195,755	$379,652	$183,897	1.94
Maintenance of equipment	235,607	625,256	389,650	2.65
Conducting transportation	720,148	1,563,682	843,485	2.17
General expense	105,120	119,760	94,640	1.90
Total operating expenses	$1,256,630	$2,768,350	$1,511,672	2.20
Gross receipts	2,484,018	3,504,847	1,020,829	1.41
Net receipts	1,227,388	736,497	490,891	0.61
Operating ratio	0.51	0.79	....	..

TABLE III

	1913	1920	INCREASE	
			Amount	Ratio
Repairs to locomotives	$88,875	$280,463	$191,588	3.15
Enginemen and roundhouse	72,931	236,673	163,742	3.24
Fuel for locomotives	244,202	359,071	114,869	1.45
Train service	80,295	200,008	119,713	2.49
Total	$486,303	$1,076,215	$589,912	2.21

The actual rise in the 19 miles is approximately 3500 ft., equal to an uncompensated grade of 3.5 per cent. With the exception of the first 2.5 miles of this heavy grade just out of Encinar there is practically no tangent track, but continuously reversing curves, many of which are on a radius of 251 ft. equivalent to 16.5 deg.

In locating the line it was apparently intended not to let the uncompensated grade exceed 4 per cent as a maximum and to keep the maximum curve at 16.5 deg. During the study it was learned that some new consolidation-type locomotives, that had been recently purchased and were temporarily being used on this division, had failed to handle satisfactorily the weight of train they had been calculated to handle on the heavy grade.

These engines were expected to be capable of taking a trailing load of 250 tons up the mountain grade. It was found, however, that it was not practicable for them to take more than 175 tons, which represents a coëfficient of adhesion of approximately 20 per cent on a grade of 4.7 per cent. Since the profile did not indicate a grade in excess of 4 per cent or curvature greater than 16.5 deg. at any point, an investigation was made which indicated that there were certain points on the line where the engines stalled owing to the slipping of drivers, and as there was no indication that the condition of the rails at this point was responsible an engineer was sent to check the grade.

It was found that short sections of track from 300 to 500 ft. in length showed actual uncompensated grades as high as 4.4 per cent which, when properly compensated for curvature at the rate of 0.045 per deg., would make the maximum grade 5.24 per cent. The average uncompensated grade for the 1.24 miles, which represented the section of greatest difficulty was found to be 3.95 per cent; which when compensated for 16.5 deg. curvature, at the rate of 0.90 lb. per degree, is equivalent to a grade of 4.7 per cent. Accordingly this was taken to be the ruling grade for the division in the specifications for electric motive power.

The average weight of the passenger trains over the road was 215 tons but these trains varied from 165 to 350 tons.

The 32 steam locomotives that had usually been used for handling both freight and passenger trains on this division were four-cylinder Fairlie engines of English build. These engines were designed especially for mountain service, having pack-saddle type tanks for fuel oil and water over a double ended boiler, which was mounted on two 3-axle swivel trucks, all the weight being on the drivers.

The engines gave the impression of two 3-axle switching locomotives coupled with cab ends together.

The fire box was in the middle of the engines and contained two oil burners, the cab being over the central portion and the engineer located on one side of the boiler with the fireman on the opposite side. The engines ran equally well in either direction, and having a comparatively short rigid wheel base, with all weight on the drivers, at once deprived the electric locomotive of three of its usually boasted advantages.

The 32 engines were all of the same general type but of variable ages and weights as shown in Table IV.

TABLE IV

5	Weighing with full tanks	167,428 lb.
12	" " " "	216,540 lb.
10	" " " "	221,000 lb.
2	" " " "	267,885 lb.
3	" " " "	305,835 lb.

The first five of the above engines were not being used at the time, as ten new locomotives of the consolidation type had just been received and some of these were being substituted temporarily.

The weight of these new locomotives is given in Table V.

TABLE V

Weight on drivers	170,540 lb.
Weight on guiding axles	21,952 lb.
Weight of tender, loaded	119,775 lb.
Total	312,267 lb.

During the months of September and October, 1921, there had been taken over the division a total of 474 trains south bound with an aggregate tonnage of 108,749 gross metric tons, and 622 trains with aggregate gross metric tonnage of 197,220 north bound. The total hours of elapsed time, or the hours for which the engine and train crews were paid, between Orizaba and Boca del Monte, where the helper locomotives on the freight trains were usually left off, were 1574 for the south bound and 2756 for the north bound traffic; making the average times for each train over the 25.4 miles as given in Table VI.

TABLE VI

	South	North
Running	2 hr. 30 min.	3 hr. 39 min.
Delayed	49 min.	45 min.
Elapsed	3 hr. 19 min.	4 hr. 25 min.

This represented an average schedule speed of 7.66 m.p.h. and 5.7 m.p.h. respectively for the south bound and north bound trains, and an average delay of 47.4 minutes per train or 25 per cent of the running time per train.

Practically all trains, both freight and passenger, required two engines. In the case of the passenger trains both Fairlie engines were placed at the head of the train with a box car between, and with the freight trains an engine was placed at each end.

The average weight of the trains up grade was 317 metric tons, or 350 U. S. tons. The down grade tons were considerably less as almost two-thirds of the traffic was north bound.

The average wage of the enginemen and trainmen on the Mexican Railway at the time, based on an 8-hour day, or 100 miles, was approximately as set forth in Table VII.

TABLE VII

	Pesos Per Day	Dollars Per Day
Engineers	12.00	$6.00
Firemen	6.00	3.00
Conductors	11.00	5.50
Brakemen	5.28	2.69

The total cost of wages on the Orizaba-Esperanza division for the two months—September and October, 1921—was, in U. S. currency, as shown in Table VIII.

The cost of locomotive service, less wages of enginemen, for the two months is given in Table IX.

The locomotive performance combined for the two months is shown in Table X.

The corresponding estimated costs for the same passenger service and an equal freight tonnage with the electric locomotives proposed for the replacement of the steam engines is given in Table XI.

The operating data and actual costs of the steam operation for the months of September and October, 1921, as given in the accompanying tables, were taken as a basis for estimating the saving that might be expected to result from the electrification of the Orizaba-Esperanza district.

Only the items of operating costs which would be most vitally affected were considered. The estimate as submitted in the report is shown in Table XII.

The estimated cost of the electrification of the 29.5 miles, Orizaba to Esperanza, is shown in Table XIII.

TABLE X

LOCOMOTIVE PERFORMANCE

Average for September and October, 1921

ORIZABA-ESPERANZA DISTRICT

	Total or Average in Km. or Mexican Pesos	Equivalent in Miles or U. S. Dollars
Distance operated	47.4	29.5
Locomotives assigned	37	37
Locomotives in service	26.5	26.5
Kilometers run:		
Passenger	27,961	17,386
Freight	53,252	33,112
Work	3,176	1,975
Light with caboose	57,043	35,470
Light	50,563	31,440
Miscellaneous	94	58
Total	192,089	119,441
Barrels fuel oil consumed	33,518	33,518
Cost:		
Fuel oil per barrel-Mex.	2.18	$1.09
Valve oil per liter	0.49	0.28
Car oil per liter	0.25	0.14
Illuminating oil per liter	0.45	0.26
Waste per kg	0.34	0.15
Grease per kg	0.66	0.30
Kilometers run per:		
Barrel of fuel oil	5.730	3.561
Liter valve oil	38.010	13.421
Liter car oil	28.230	9.968
Kg. waste	173.400	48.881
Kg. grease	209.000	58.917
Cost per km. run:		
Fuel oil	0.38480	$0.30942
Lubricants	0.02889	0.02323
Labor repairs	0.47795	0.38433
Materials repairs	0.13847	0.11134
Enginemen	0.18720	0.15053
Hostlers and wipers	0.03631	0.02920
Total	1.25362	$1.00805
Total cost of:		
Fuel oil	73,929.09	$36,964.50
Lubricants	5,551.14	2,775.57
Repairs labor	91,814.67	45,907.33
Repairs material	26,601.19	13,300.55
Enginemen	35,966.00	17,983.00
Hostlers and wipers	6,981.62	3,490.81
Total	240,843.71	$120,421.76

TABLE VIII

	September	October	Total	Rate Per Year
Engineers	$5,788	$6,490	$12,278	$73,668
Firemen	2,687	3,017	5,704	34,224
Conductors	2,140	2,395	4,535	27,210
Flagmen	721	768	1,498	8,934
Brakemen	3,847	4,344	8,197	49,146
Total	$16,183	$17,014	$32,197	$193,182

TABLE IX

	September	October	Total	Rate Per Year
Fuel oil	$19,413	$17,552	$36,965	$221,790
Repairs	30,426	28,782	59,208	355,248
Enginehouse	1,206	2,185	3,391	20,346
Lubricants	1,364	1,412	2,776	16,656
Total	$52,409	$49,931	$102,340	$614,040

TABLE XI

ESTIMATED OPERATING COSTS OF ITEMS DIRECTLY AFFECTED BY ELECTRIFICATION

Based on Tonnage Carried During Months of September and October, 1921

ORIZABA-ESPERANZA DISTRICT

	FREIGHT				PASSENGER
PROPOSED TRAIN RATING, TRAILING	600 TONS	600 TONS	900 TONS	1200 TONS	300 TONS
NUMBER OF ENGINE CREWS PER TRAIN	1	2	2	2	1
Gross tons trailing per year, northbound	1,053,756	1,053,756	1,053,756	1,053,756	......
Average tons per train, northbound	540	540	810	1,080	300
Total number of trains, northbound	1,951	1,951	1,301	977	521
Locomotive units per train	2	2	3	4	1
Locomotive unit miles per trip	120	120	180	240	60
Locomotive unit miles per year	234,120	234,120	234,180	234,480	31,260
Locomotive unit miles, work and miscellaneous	23,480	23,480	23,480	23,480	3,140
Total	257,600	257,600	257,660	257,960	34,400
Cost per trip, enginemen (U. S. dollars)	$9.68	$17.60	$18.48	$19.36	$8.56
Total cost per year	18,886.00	34,338.00	24,043.00	18,915.00	4,460.00
Cost per trip—trainmen	11.88	10.80	11.88	11.88	10.80
Total cost per year for trainmen	23,178.00	21,071.00	15,454.00	11,607.00	5,627.00
Total cost per trip—wages	21.56	28.40	30.36	31.24	19.36
Wages per year	42,064.00	55,409.00	39,499.00	30,522.00	10,087.00
Add 10 per cent for overtime and miscellaneous	4,197.00	5,541.00	3,950.00	3,053.00	1,009.00
Grand total, wages per year	46,267.00	60,950.00	43,449.00	33,575.00	11,096.00
Kilowatt demand	4,000	4,000	6,000	8,000	*
Approximate cost per kilowatt per year	$33.34	$33.34	$25.00	$25.00	......
Approximate cost per year	134,000.00	134,000.00	150,000.00	200,000.00	......
Cost of locomotive repairs per year	45,080.00	45,080.00	45,090.50	45,143.00	$6,020.00
Cost of locomotive repairs, enginehouse, per year	5,152.00	5,152.00	5,153.20	5,159.20	688.00
Cost of lubricants per year	2,576.00	2,576.00	2,576.60	2,579.60	344.00
Total cost per year	233,078.00	247,758.00	246,269.30	286,456.80	18,148.00
Grand total, including passenger	251,226.00	265,906.00	264,417.30	304,604.80	......
Maximum number of trips per day	•10	10	7	7	2
Maximum gross tonnage per day	6,000	6,000	6,300	8,400	600
Normal number of trips per day	6	6	4	3	2
Normal tonnage per day	3,240	3,240	3,240	3,240	600

*No charge is made for power for passenger train since the purpose of the tabulated comparison is primarily to determine the desirable train weight to adopt.

It is assumed that the northbound tonnage will determine the number of train trips and that each train northbound will incur the expense of an entire round trip.

TABLE XII

	Steam	Electric	Saving	Ratio Steam to Electric
Wages of enginemen	$108,892	$31,354	$76,638	3.44
Wages of trainmen	85,290	23,191	62,099	3.68
Fuel and power	221,790	150,000	71,790	1.48
Repairs to locomotives	255,248	51,111	304,157	6.95
Enginehouse expense	20,946	5,841	15,105	3.57
Lubricants	16,656	2,921	13,735	5.70
Substation operation and maintenance	....	11,750	....	....
Maintenance distributing system	....	9,625	....	....
Total	$808,822	$285,793	$523,029	2.82

TABLE XIII

Ten 150-ton electric locomotive units	$1,420,000
One 6000-kw. substation	350,000
Thirty route-miles distributing system	430,000
Engineering and contingencies	220,000
Total gross capital investment	$2,420,000

The report accordingly indicated a probable saving of $523,029 per year by the expenditure of approximately $2,420,000, or a return of slightly more than 21 per cent on the gross investment, which included electric locomotives.

A similar study of the line between Orizaba and Paso del Macho was made at the same time, but as the probable savings indicated a return on the required investment only about half that estimated for the Orizaba-Esperanza district, the report recommended that only the latter be undertaken in the beginning.

After a very careful examination of the report by the operating department of the railway it was approved and recommended to the board of directors.

In October, 1922, a contract was made for the required equipment and materials, including the general supervision of the installation.

Actual work on the ground was begun in January, 1923, and the work was completed and all trains were being hauled electrically by January, 1925.

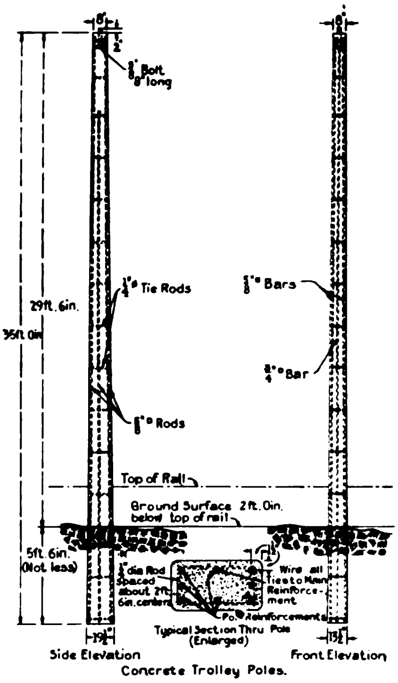

Bolt 8" long
Tie Rods
Bars
Bar
Rods
29ft. 6in.
35ft. 0in
Top of Rail
Ground Surface 2ft. 0in. below top of rail
5ft. 6in. (Not less)
dia Rod Spaced about 2ft. 6in. centers
Wire all Tie to Main Reinforcement
Pole Reinforcement
Typical Section Thru Pole (Enlarged)
Side Elevation
Front Elevation
Concrete Trolley Poles.

Fig. 7. Details of Concrete Trolley Poles

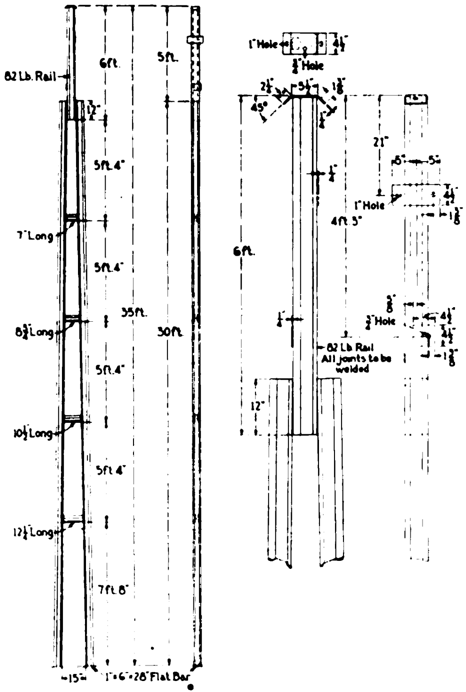

82 Lb. Rail
6ft.
5ft.
5ft. 4"
7" Long
35ft.
30ft.
8½ Long
10½ Long
12½ Long
7ft. 8"
1"×6"×28" Flat Bar
1" Hole
45°
21"
4ft. 5"
6ft.
12"
82 Lb Rail All joints to be welded

Fig. 8. Details of Welded Steel Pole Made from 62-lb. and 82-lb. Rails

TABLE XIV

DETAILED COST OF MAKING 405 CONCRETE POLES

Items	Quantities	Total Cost	Cost Per Pole
Cement at $1.05 per sack (including freight)	7 sacks per pole	$2,976.75	$7.35
Gravel at $3.60 per meter (including freight)		1,113.75	2.75
Sand at $1.00 per meter (including freight)		202.50	0.50
Reinforcement bars ¾-inch and ⅝-inch	69.3 tons	6,299.10	15.55
Reinforcement wire ¼-inch	2.1 tons	197.78	0.49
No. 6 welding wire	330 lb.	85.50	0.21
No. 9 welding wire	225 lb.	61.36	0.15
Old telegraph wire	1423 lb.	48.52	0.12
Electric current	Approx.	299.00	0.74
Oxygen	9 bottles	75.00	0.18
Carbide	154 lb.	8.70	0.02
Hut for storing cement, material		440.00	1.10
Forms and bottoms, material	9 forms	490.25	1.21
Other material for plant		322.13	0.80
Wages, Locomotive Dept.		569.50	1.41
Wages, Engineering Dept.		295.75	0.73
Wages, Eng. Dept.—bridges and buildings		153.00	0.38
Amount paid to contractor—cement work		1,612.00	4.00
Amount paid to contractor—reinforcement		776.05	1.92
Total		$16,026.64	$39.60
Overhead charges, superintendency, etc. 15 per cent		2,403.98	5.92
GRAND TOTAL		$18,430.43	$45.52

The work was almost entirely stopped from the middle of December, 1923, to May, 1924, by the rebellion that occurred at that time; just when the construction work had been fully organized and gotten well under way. This interruption caused several months' delay and considerably increased the cost of the work.

The work was done almost entirely with native labor which had to be trained. Three supervising engineers were placed in direct charge of the distribution, the substation, and the locomotives, respectively, reporting to the resident engineer of the railway Company, in coöperation with the general engineer of the contractor.

The Distribution System

The simple catenary system, with double 4/0 trolley on the main line and single 4/0 trolley in yards and passing tracks, similar to that used on the Chicago, Milwaukee and St. Paul, was adopted. Concrete poles were first selected for the supporting structure; but it was found that several hundred old 30-ft., 82-lb. rails, which had been replaced, were on hand and that there was no market for these where the price offered would justify handling and transportation charges.

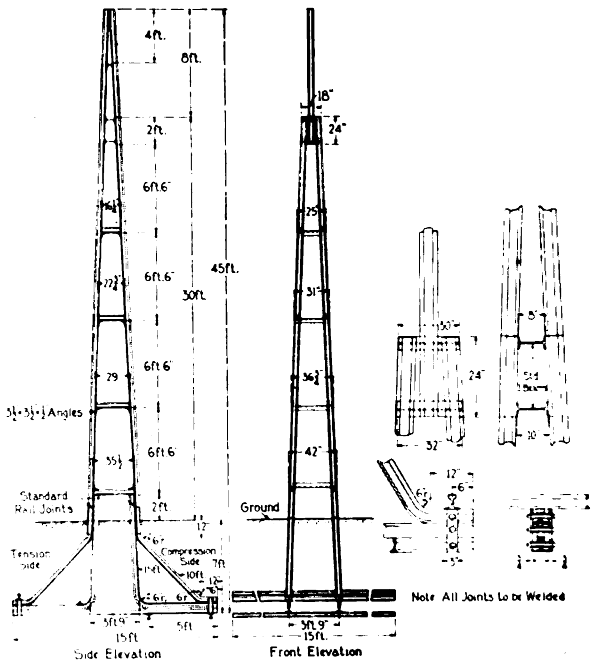

4ft.
8ft.
2ft.
6ft. 6"
45ft.
30ft.
18"
24"
25
31
36½
42
27½
29
35½
5½×3½×½ Angles
Standard Rail Joints
Tension Side
Compression Side
Ground
15ft.
5ft. 9"
Side Elevation
Front Elevation
Note All Joints to be Welded

Fig. 9. Details of 45-ft. Welded Rail Tower for Orizaba Yard

Some sample poles were made up from these rails by electric welding and were tested for deflection and breaking strains, which resulted in a decision to use these as far as the rails would supply the demand. Of a total of 1920 poles made, 405 were of concrete as shown in Fig. 7. and 1515 were made up of old rails (see Fig. 8).

Detailed costs of each type of pole are given in Tables XIV, XV, and XX.

Unit costs of various items relative to the work in connection with the setting of poles are given in Table XVI.

All this work was done by contract, the unit price being fixed after sufficient experience had demonstrated a fair basis.

Details of the concrete poles are shown in Fig. 7. Figs. 8 and 9 show respectively the dimensions of the welded steel poles and towers which were made in the railway shops from old rails which had seen many years of service. Fig. 10 shows some interesting special construction work typical of that used on

TABLE XV
DETAILED COST OF MAKING 1419 RAIL POLES

Items	Quantities	Total Cost	Cost Per Pole
82 and 62-lb. rail at 1 ct. per lb.		$20,575.50	$14.50
$\frac{3}{16}$-plates	5,500 lb.	50.00	0.03
No. 6 welding wire	871 lb.	226.86	0.16
No. 9 welding wire	4,114 lb.	1,103.48	0.78
Old telegraph wire	12,770 lb.	469.35	0.33
Electric current, approximate		1,443.00	0.02
Oxygen	9 bottles	75.00	0.05
Gasoline	100 gal.	28.12	0.02
Carbide	154 lb.	8.52	0.01
Installation of plant—materials		*5,582.13	3.93
Upkeep of plant—materials		650.90	0.41
Wages, Locomotive Dept		1,873.50	1.32
Wages, Engineering Dept		2,750.00	1.98
Amounts paid to contractor		6,901.50	4.86
Amounts paid for cutting		176.19	0.12
Amounts paid in compensation		73.02	0.05
Total		$41,987.57	$29.57
Overhead charges, superintendence, etc., 15 per cent		6,298.13	4.43
GRAND TOTAL		$48,285.70	$34.00

*Including cost of two arc welding machines, $3,562.50.

TABLE XVI
DETAILED COSTS OF LABOR ITEMS OF CONSTRUCTION WORK

Number	Items	Unit Cost
405	Making concrete pole	$4.03
	Making concrete anchor	0.20
1120	Digging pole hole, earth	0.75
78	Digging pole hole, tepetate	0.95
521	Digging pole hole, loose rock	1.75
191	Digging pole hole, solid rock	8.00
	Average for 1910 holes	2.00
392	Setting concrete pole	1.70
1400	Setting rail pole	1.78
105	Distributing rail poles cutoffs	7.77
4	Towers Wimmer Bridge	43.75
42	Towers Orizaba yard	59.36
1483	Anchor holes	1.21

TABLE XVII
LABOR COST OF PUTTING UP TROLLEY, FEEDERS AND FITTINGS
ORIZABA-ESPERANZA 29.5 MILES

	Hours	Dollars	Cents Per Hour
Foremen	12,800	$7,953	62.1
Assistant Foreman	11,215	4,564	40.6
Linemen	34,612	9,563	27.6
Helpers	40,516	6,078	15.0
Laborers	43,769	4,658	10.6
Office Emp.	4,376	572	13.0
Total	147,288	$33,388	22.7

TABLE XVIII
LABOR COSTS OF MALTRATA SUBSTATION INSTALLATION—6,000 KW.

	Hours	Dollars	Cents Per Hour
Foremen	1,408	$1,308	92.9
Electrician 1st	4,868	2,237	45.7
Electrician 2d	5,214	1,490	28.6
Helpers	2,959	444	15.0
Mechanics	1,000	401	25.0
Pipe fitters	385	120	31.2
Storekeeper	524	57	10.9
Laborers	9,825	1,134	11.5
Operators	960	325	33.9
Total	27,143	$7,516	27.6

TABLE XIX
COST OF INSTALLING 11,551-250,000 CIR. MIL 14-INCH ELECTRICALLY-WELDED BONDS

2292 gallons gasoline	$736.56
78 gallons valve oil	93.60
34 gallons machine oil	57.12
1776 hours labor	6,177.49
Total cost	$7,064.77
Average cost per bond—cents	61.16

TABLE XX
DETAILED ESTIMATE OF COST OF MAKING 812 RAIL POLES
ORIZABA-CORDOBA

Items	Quantities	Total Cost	Cost Per Pole
82 and 62-lb. rail	1,363,023 lb.	$13.466.78	$16.585
Welding wire	11,340	678.40	0.835
Electric current, approx.	29,232 kw.	584.64	0.720
Oxygen	18 bottles	182.28	0.224
Gasoline	5 gal.	1.99	0.003
Carbide	640 lb.	34.80	0.042
Wages Locomotive Dept.		33.58	0.041
Amounts paid to contractor, labor		4,359.25	5.368
Amounts paid for cutting rail	3735 pieces	205.42	0.252
Amounts paid in compensation		9.65	0.011
Total		$19,556.80	$24.08
Overhead charges, superintendence, etc., 15 per cent		2,933.52	3.61
GRAND TOTAL		$22,490.32	$27.69

bridges; and Figs. 11, 12, 13, and 14 can be taken as general examples of the types of overhead construction.

Bracket construction was used where possible except where the poles supported feeder wires and it was desirable to avoid crossing over the tracks too often. In such cases, as between Boca del Monte and Alta Luz, the feeder cables were kept on the upper side of the track by having the poles continuous on that side irrespective of the curves, thus using cross-span supports where the curves were outward from the upper side of the slope. This also prevented interference with the magnificant view from the car windows overlooking the valley.

TABLE XXI

DETAILED ESTIMATE OF COST OF MAKING 33 RAIL TOWERS (Fig. 9)

ORIZABA-CORDOBA

Items	Quantities	Total Cost	Cost Per Pole
62-lb. rail	65,560 lb.	$892.38	$27.042
Iron beam	1114 lb.	60.63	1.837
Welding wire	1500 lb.	90.23	2.734
Electric current, approx.		71.28	2.160
Oxygen	2 bottles	24.40	0.739
Gasoline	0.66 gal.	0.28	0.008
Carbide	86 lb.	4.66	0.141
Wages, Locomotive Dept.		4.49	0.136
Amounts paid to contractor		1,320.00	40.000
Amounts paid for cutting	544 pieces	29.92	0.907
Amounts paid for	340 bends	425.00	12.878
Amounts paid in compensation		1.30	0.039
Total		$2,924.57	$88.62
Overhead charges, superintendence, etc. 15 per cent		438.68	13.30
GRAND TOTAL		$3,363.25	$101.92

TABLE XXII

DETAILED ESTIMATE OF COST OF MAKING 18 RAIL TOWERS

ORIZABA-CORDOBA

Items	Quantities	Total Cost	Cost Per Pole
40-lb. rail	4200 lb.	$57.65	$3.185
62-lb. rail	13390 lb.	182.22	10.123
82-lb. rail	22625 lb.	205.30	11.405
Iron beam	7130 lb.	388.01	21.555
Welding wire	830 lb.	49.60	2.755
Electric current, approx.		38.08	2.143
Oxygen	1 bottle	13.31	0.739
Gasoline	0.4 gal.	0.15	0.008
Carbide	46 lb.	2.54	0.141
Wages, Locomotive Dept.		2.45	0.136
Amounts paid to contractor		225.00	12.50
Amounts paid for cutting	297 pieces	16.34	0.908
Amounts paid in compensation		0.71	0.039
Total		$1,181.36	$65.64
Overhead charges, superintendence, etc., 15 per cent		177.20	9.84
GRAND TOTAL		$1,358.56	$75.48

In addition to the two 4/0 trolley wires, two 500,000 cir. mil positive feeders and one 4/0 negative feeder cable were installed from Orizaba to Boca del Monte. The feeders were carried on separate poles at four points where the rail line made long loops. The advantage thus gained was the reduction of feeder length from 29.5 miles to 20.4 miles. The single substation for the 29.5 miles was located near Maltrata, which is almost midway in the feeder circuit. Only a single 500,000-cir. mil feeder was used between Boca del Monte and Esperanza as the grade here was comparatively light.

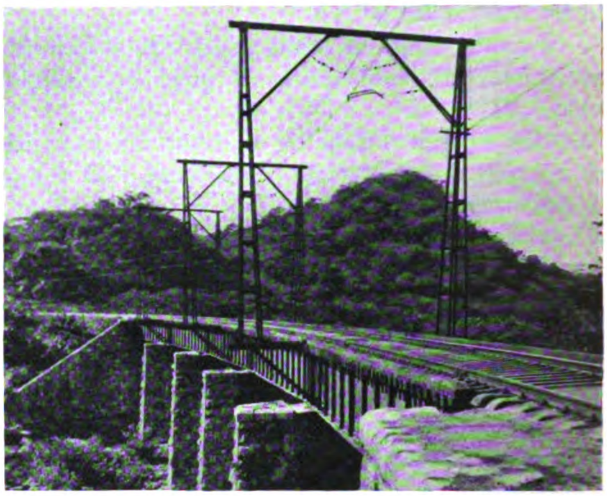


Fig. 10. Special Overhead Construction on Bridge at Rio Seco

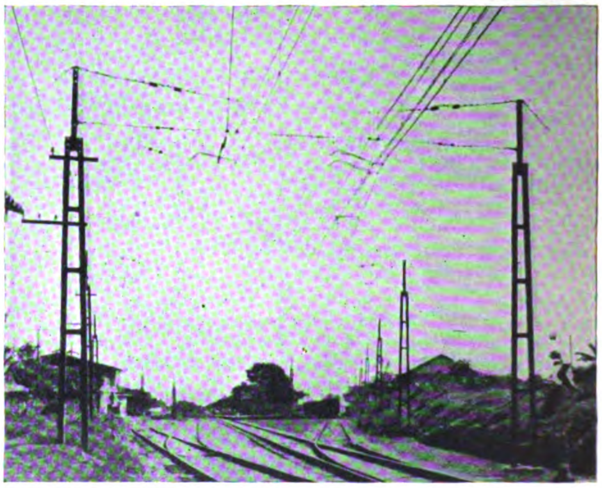


Fig. 11. Overhead Construction at Entrance to Parage Nuevo Yard

A similar feeder was used from the substation to the middle of the Bota loop, making it unnecessary to install any feeders along the rail line between Bota and Alta Luz, where the curvature was greatest, since this loop was fed from both ends making the equivalent of a double-track circuit.

The voltage drop over the entire line, with a 665-ton freight train on the upgrade, indicates a maximum drop of 400 volts, or 13 per cent, the average drop being 235 volts or 7.6 per cent.

A single 250,000-cir. mil electrically-welded bond was used throughout. Pressed steel track ties were in use over most of the line and were being used to replace wooden ties as required.

The trolley and feeder lines were sectionalized at Nogales, Maltrata, Alta Luz, and Boca del Monte.

At Orizaba the yards consisted of eight tracks, located between the shops on one side, and the station, storehouses, and roundhouse on the other side.

At many points the ground was soft and the use of guy wires objectionable. So towers were made up from 62-lb. discarded rails which were capable of supporting the wiring necessary for the 8 tracks. Special extensions were made which provided foundations at a reasonable cost and which rendered guying at any point unnecessary.

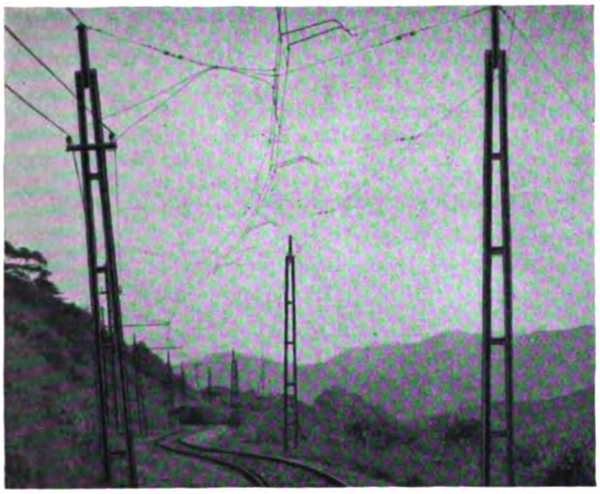


Fig. 12. View of Overhead Line South of Boca Del Monte

Drawings showing the dimensions of the 44 towers used in the Orizaba yard are shown in Fig. 9. Thirty-three similar towers were used in the Cordoba yard, detailed costs of which are shown in Table XXI. Other lighter towers also made from old rails, costs of which are given in Table XXII, were used at bridges. The Metlac bridge on a 16-deg. curve, where 18 towers were required, is the longest.

TABLE XXIII

DETAILED COST OF 25.9 KM. (16 MILES) DISTRIBUTION SYSTEM

ORIZABA TO CORONA

No.	Items	Amount	Per Route Mile
818	Rail poles, line	$22,656.46	$1,416.03
34	Rail towers, yard	3,456.17	216.57
22	Rail towers, bridge	1,660.47	103.78
	Wire and fixtures	148,123.27	9,257.70
	Stone and cement	1,855.37	115.96
	Work cars and equipment	2,742.68	171.42
	Miscellaneous	9,085.27	567.83
	Total material	$189,588.69	$11,849.29
229	Work trains	$14,011.82	$876.17
	Erection of poles and towers	10,869.62	679.35
	Erection of wires, etc	9,879.60	617.48
6008	Bonds installed	2,513.36	157.09
	Engineering and supervision	6.686.72	417.92
	Total installation	$43,967.12	$2,727.95
	GRAND TOTAL	$233,555.81	$14,597.24

There were seven tunnels on the first electrification, six on the Cordoba and two on the Paso del Macho extensions, a total of 15, all but two of which were on curves.

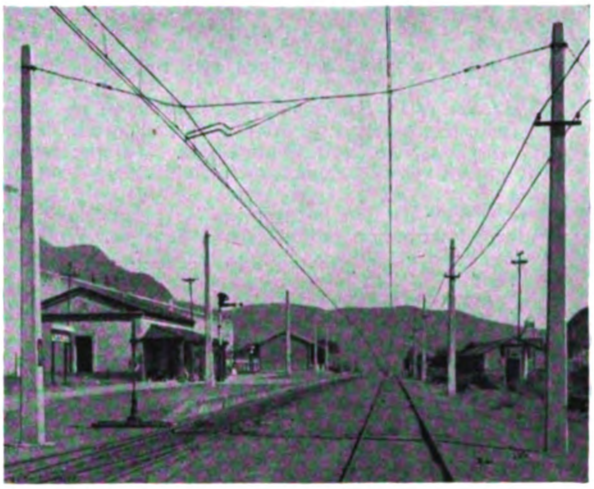


Fig. 13. Overhead Line in Nogales Station, Showing Span Construction Concrete Poles

The total cost of the 29.5 miles of distribution system, including poles and fixtures, was $462,011 or $15,661 per route-mile.

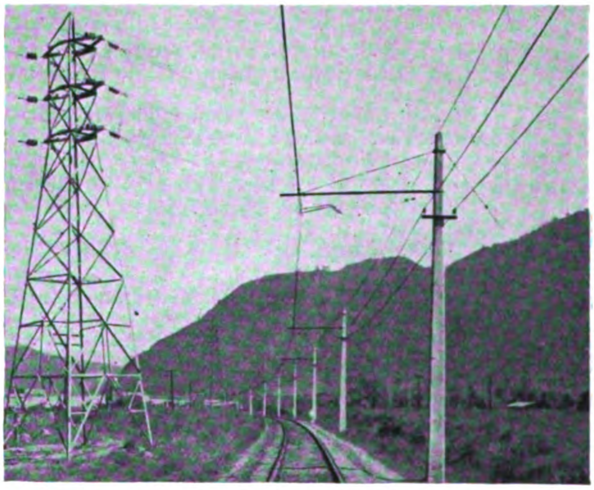


Fig. 14. 3000-volt D-c. Electrification. 42,000-volt Transmission Line Crossing the Railroad Company's Tracks

In 1926 the trolley line was extended from Orizaba to Cordoba, 16 miles south, making a stub-end feed from the Maltrata substation approximately 29 route-miles in length; but feeder cut-offs at loops reduced the feeder to about 25 miles. This construction was similar to the original except that rail poles were used exclusively. Two 500,000-cir. mil copper feeders were used almost the entire distance. Detailed costs of this construction are given in Table XXIII. The total was $233,556 or $14,597 per route-mile. The estimated cost was $231,500, but did not include the complete wiring of the Cordoba yard as was done.

(To be continued)

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Condensed references to some of the more important recent articles in the technical press, and to new books of interest to the industry, as selected by the General Electric Main Library.

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Engrs. Soc. of W. Pa. Proc., Apr., 1929; v. 45, pp. 134-163.
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("A complete textbook for students of wireless communication" and intended to be "of instructional value to non-technical students and readers generally." To this end the authors have devoted considerable space to the fundamental principles of electricity and magnetism, and to consideration of many allied electrical phenomena and devices which have a bearing on the radio science proper. Magnetism, production of electromotive force, generators, motors, storage batteries, meters, alternating currents, and the like, are given considerable attention in order that the reader may be enabled to grasp the strictly radio topics which follow. These latter embrace: condensers and capacity, vacuum tubes, receiving circuits, alternating-current receivers and tubes, loudspeakers, rectifiers and filters, antennas, resonance, commercial receivers and transmitters, the various types of transmitting equipment, direction finders, and broadcasting transmitters. An appendix contains useful data for calculation and operation of radio apparatus.)

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(The authors say: "We have attempted to give a true picture of the state of television today and to give the reader the necessary background to enable him to begin a special study of any one feature. Our style, we hope, is also of a sufficiently popular nature to enable the layman to gain a proper perspective of the subject. The book is in no sense a compendium." After the introductory chapters on elementary principles, historical development of television, and optical systems and the eye, we are given chapters on electromagnetic waves, selenium and photoelectric cells, glow lamps, oscillographs, scanning, synchronizing, telephotography, the Baird, Bell, Jenkins, and Alexanderson systems of television, and a short chapter venturing a prediction as to the possible future of television.)

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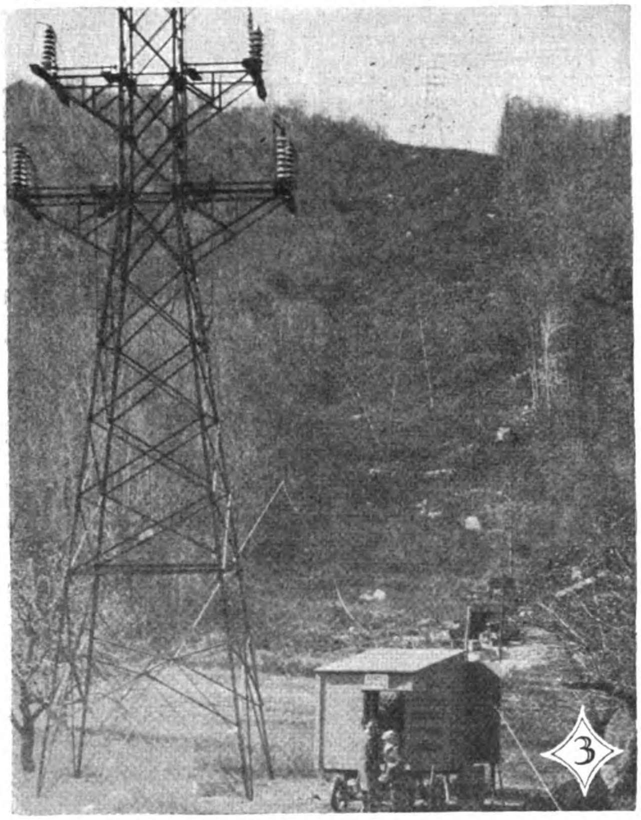
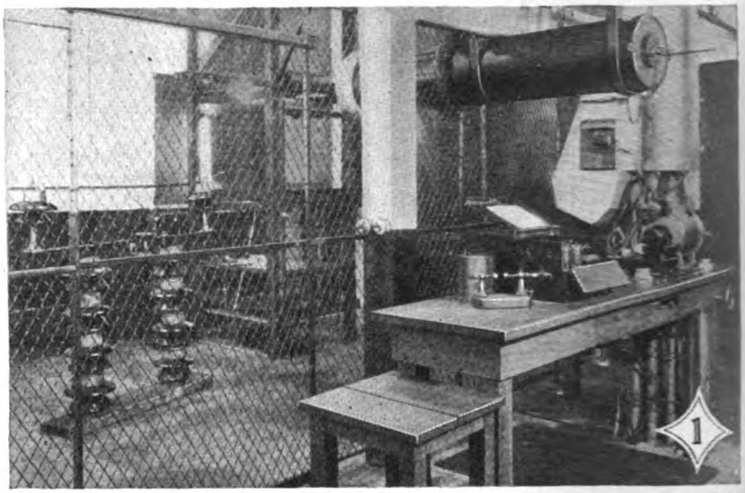
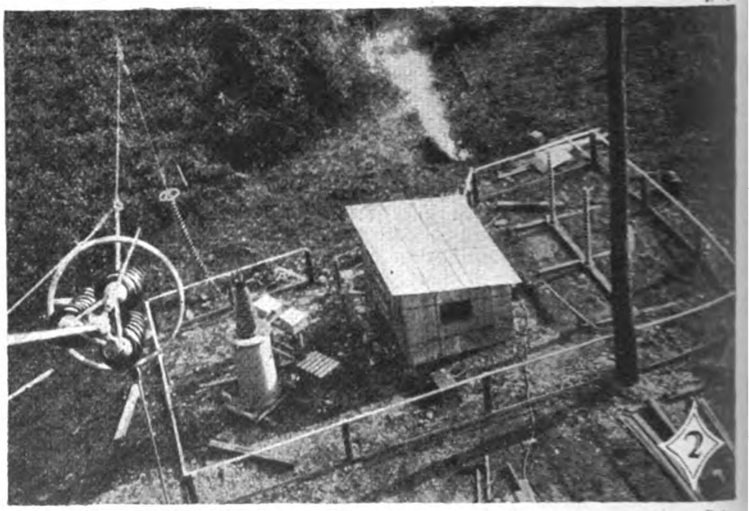
Mastery of Lightning

will require complete knowledge. G-E engineers are near that goal







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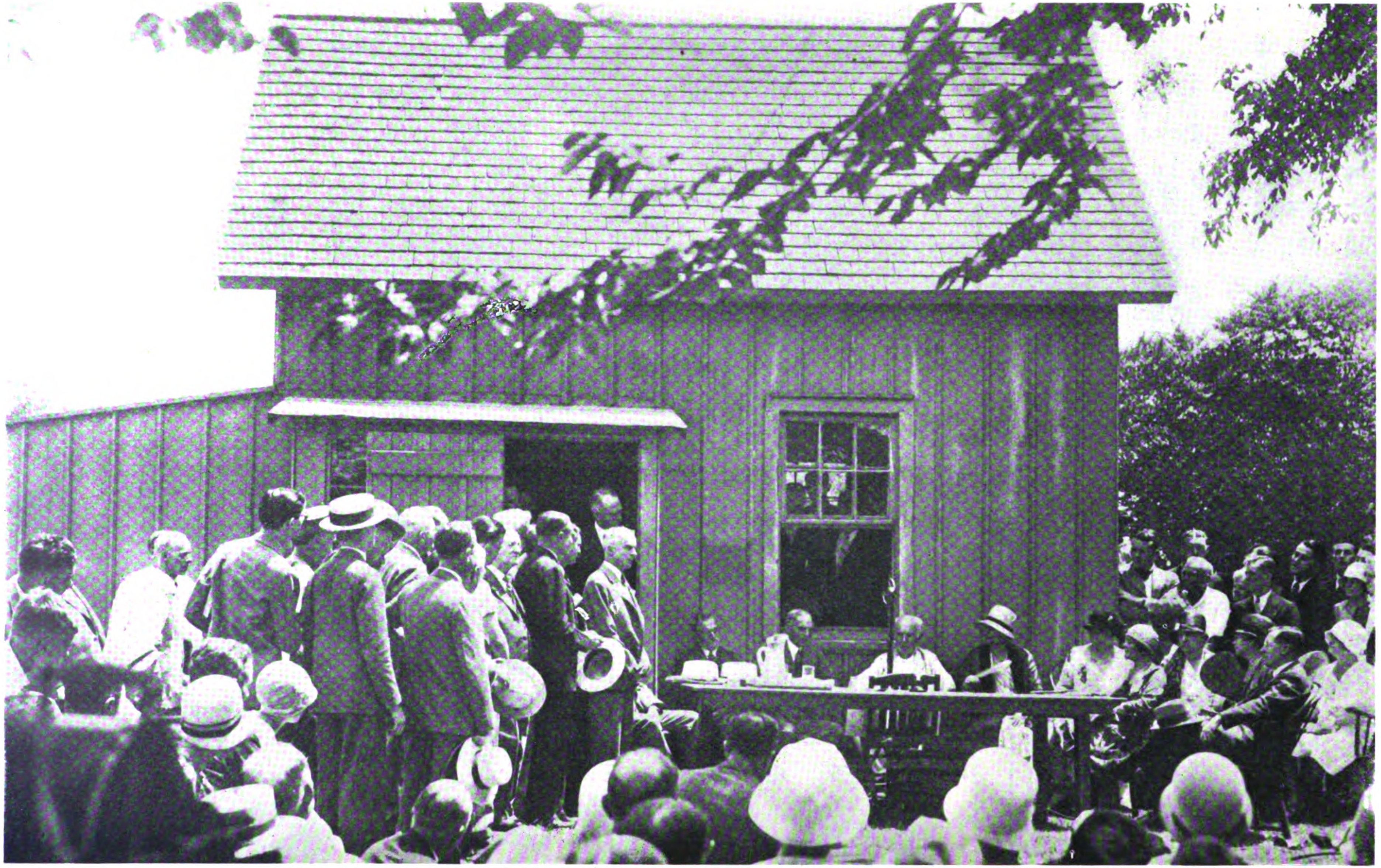


World Wide Photos

AN HISTORIC EVENT IN THE CELEBRATION OF LIGHT'S GOLDEN JUBILEE

The original lamp factory of Edison's early Menlo Park days, in which birth was given to the electric lamp now being commemorated by Light's Golden Jubilee. In the presence of Thomas A. Edison and others, this historic building was formally presented on June 22, 1929, to Henry Ford, who will give it a place of honor in the Edison Memorial Institute at Dearborn (Mich.). Mr. Edison and Mr. Ford are shown seated at the far side of the table with Mrs. T. A. Edison and John W. Lieb. The ceremony was opened by George C. Osborn, who is sales manager of the Edison Lamps Works of the General Electric Company and who is shown standing at the left end of the table. While Mr. Ford takes title to the building, its key will remain in the possession of Mr. Edison

(A description of the lamp appeared in our May, 1929, issue)

GENERAL ELECTRIC REVIEW

Vol. 32 October, 1929 No. 10

EDISON

Once upon a time a small boy, six years of age, was missing from home and, after a prolonged search, was found in the barn sitting on a nest he had constructed himself and had filled with goose and hen's eggs. He had observed nature and was questioning her in an extraordinarily intelligent and practical way. The boy's name was Thomas A. Edison.

His second experiment has more human interest attached to it, as the subject was the farmhand this time; a lad both bigger and older than the boy Edison. Our young experimenter had spent all of his available cash in purchasing a large number of Seidlitz powders and compelled the bigger boy to swallow them all as fast as he possibly could. The results have never been accurately and fully recorded. But Edison does acknowledge that his firm belief, that the gas generated would enable the subject of his experiment to fly, was without foundation!

When Edison was a little older he tried to operate an electric telegraph he had constructed by using the family cat as a frictional machine. He assures us that the only reasons why the experiment failed were: (1) the cat was not as interested in science as he, (2) the cat strenuously objected to the severe rubbing process, and (3) the cat could run faster than he.

This year we are celebrating "Light's Golden Jubilee," to commemorate some of the outstanding work of the man who, as a boy, made these experiments. As probably most of our contemporaries will largely devote their remarks to Edison's work in developing his incandescent lamp, we wish to say something about the man.

If you were to examine every leaf on a tree you wouldn't find two exactly alike. If you were to examine every leaf in the whole forest no two could be found exactly alike—and so it is with boys and men. Edison was different—he had more everlasting inquisitiveness and curiosity and displayed more originality, tried more experiments, and showed more patience and perseverance than any boy we have ever read or heard of. It was the possession of these priceless gifts, combined with a character that used them to the full, that has given us the name we are delighted to honor—the name of Edison.

We regard it as an extraordinarily fortunate thing, both for Mr. Edison and the world at large, that he never had more than three months at school during his whole life. Genius and originality are both tender things in youth and can be readily suppressed by lack of sympathy and understanding. Education can put nothing into a skull, but it can train and develop what the skull contains. You can learn more by observation and experiment than by explanation. It is these facts that make the path of the educator so hard, and render it so much easier to criticize his work than to make suggestions for improvements.

You must have something in the skull worth developing, and Edison seems to be a striking example that proves that when it is there it can be developed outside the schoolroom.

Edison was born an inventor and experimenter and has been hard at it for the last 76 years. He is 82 years old now and he started at six.

During this time we believe that Edison has taken out over 1000 patents—he has more patents to his credit than any other man on the earth.

Edison has spent his entire time in trying to do something useful—and in succeeding.

We are not going into details of his life's work here, but will refer our readers to our issue of April, 1924, where we gave a brief account of his most important undertakings. All of his efforts have been directed to trying to make something a commercial success. Here we should like to emphasize one thing that we believe is not generally understood about Mr. Edison's character. Although his entire life has been spent in inventing and developing things for commercial use, he has absolutely no desire for money for the sake of possessing money. To use his own words, the only reason why he wanted to make money was so that he could make more experiments.

The very fact that we can title our present editorial with a single word and that that single word fully describes our subject is the most eloquent tribute to America's Grand Old Man. Probably there is no name in history that has ever been known, especially during the life of the individual, by a greater percentage of the world's population than the name Edison.

America may justly be proud of the fact that the word, Edison, is synonymous with invention and genius throughout the world, and is, therefore, symbolic of those high human characteristics that have played the major role in giving to the new world that preëminent position that she occupies in industry and commerce.

Mr. Edison, together with all those others who are celebrating "Light's Golden Jubilee," we salute you, with respect, affection, and admiration, and thank you for your many contributions to human progress.

J. R. H.

Light's Golden Jubilee

By **J. F. QUINLAN**

Executive Secretary, Light's Golden Jubilee

THE widespread observance of Light's Golden Jubilee, marking the 50th anniversary of the incandescent lamp, is just as much an occasion for serious retrospect, profound appreciation, and genuine inspiration as it is a celebration, gala, festive, and jubilant. It is a celebration limited to no one company, to no one industry, nor to any single nation. Light's Golden Jubilee offers the electrical industry a golden opportunity to join with the world at large in paying the greatest tribute ever paid to a living man.

The Jubilee received its first formal suggestion on Edison's eighty-second birthday. At a luncheon of the Edison Pioneers, their fellow member, John W. Lieb, tentatively outlined the celebration. The Pioneers then unanimously approved the following resolution:

> "*Resolved*, that the President of the Edison Pioneers be requested, and he is hereby authorized to appoint a committee of five from its membership to propose to the electrical industry at large, the organization of a Sponsoring Committee which may prepare plans for the appropriate celebration of the Golden Jubilee of the Incandescent Lamp occurring during the year 1929."

The preliminary light festivals this summer have been notable. Light's Golden Jubilee was brilliantly inaugurated at Atlantic City on May 31st. In the presence of Vice President Curtis, Preston S. Arkwright, President of the National Electric Light Association, delivered the address which opened the ceremonies, a feature of which was a spectacle of light that bathed the land and sea in all the hues of the rainbow.

Two weeks later the City of Niagara Falls dedicated its Fifth Annual Festival of Light to the celebration of Light's Golden Jubilee. All of the principal streets were flooded with golden light, and the Falls were illuminated by a battery of searchlights aggregating 1,440,000,000 c. p.

Saturday, August 31st, was Edison Day at the National Air Races, Cleveland (O). At ten o'clock in the evening an open-air show was held, attended by a number of distinguished guests and over 15,000 people. Tributes to Edison were paid by leading men in aviation; and air-mail pilots vied with each other in a race to Milan (Edison's birthplace) and return. All of these festivities were broadcast over nation-wide hook-ups.

The opening night of the National Convention of the American Legion, our country's largest convention, to be held in Louisville (Ky)., September 30th to October 3rd, will be dedicated to Thomas Edison and Light's Golden Jubilee.

Besides the acceptance of the Honorary Chairmanship of the National Sponsoring Committee by the President of the United States, our government has issued a special two-cent postage stamp to commemorate the Jubilee. The manner in which this stamp has been received by the country at large is evidence of the great interest on the part of the public. Three hundred and thirty millions of these stamps have been purchased since June 5th. Mr. Edison wrote the following letter to the Postmaster General, Walter F. Brown, in appreciation of this honor:

> "Honorable Sir:
>
> I wish to thank you most heartily for the very gracious recognition of my invention of the incandescent lamp, through the issuance of a special stamp, the first impression of which you have so kindly sent me. I assure you that the stamp and your expression of appreciation will be highly prized by me. THOMAS A. EDISON, 6/8/29"

Captains of industry and finance, and a distinguished group of men and women representing practically every walk of life in America made up the personnel of the National Sponsoring Committee. Henry Ford considers Light's Golden Jubilee "his job of the year" and made this comment to the writer recently when he visited Mr. Ford at Dearborn (Mich.). All of us are familiar with Mr. Ford's manner of doing things, and it is safe to say that the culmination of Light's Golden Jubilee at Dearborn on the night of October 21st will be recorded as one of the finest tributes ever given to any living person.

Meanwhile, in large cities and small towns in every part of the land, extensive preparations are being made for local participation in the Jubilee by street parades, lighting and fireworks displays, dinners, meetings, etc. In recognition of these activities, the governors of Arizona, California, Florida, Idaho, Indiana, Kentucky, Maine, Maryland, Massachusetts, New Mexico, Michigan, New Hampshire, New Jersey, Ohio, Oregon, South Carolina, Texas, Utah, Wisconsin, and Wyoming will issue proclamations or statements to the press prior to October 21st. So, truly, our country will stand by in honor of Mr. Edison and his lamp.

The central stations of the country are coöperating to show their appreciation to the man whose works mark the beginning of the central-station industry. Every central station thus has a two-fold opportunity: first, of active direct participation; and second, of encouraging others to take part.

An Example of the Use of Observation

By DR. W. R. WHITNEY
Vice President and Director of Research
General Electric Company

The following brief article was composed from notes that Dr. Whitney made for an address he gave this summer at "Camp General," Association Island. It is of interest as showing how the observation and recording of at-the-time apparently trivial phenomena may lead to results of great value at a later date.

—*Editor*

As an interesting little detail of the great fabric of coördinated research, picked out of the cold insides of our electric refrigerator, I like to think of the welded joints in the triple-concentric containers which form the substitute for the ice cakes, the so-called evaporator inside the refrigerator box. The front edge of the open cubicle is a three-ply welded joint where three separate boxes of sheet iron are sealed one within the other. This welded edge had to possess several qualities. In the first place it must be stiff, and strong, and thick enough to hold permanently the mineral enamel which covers it. It must also be solid enough so that contraction and expansion of the parts will not produce appreciable yielding, and thus crack the enamel. It must be smooth and clean. It must never leak a trace of the high-pressure gas behind it, nor let gas and water intermingle around the intermediate barrier. In this small area of edge, which can be represented by an inch of material, two new methods of welding are used both of which were developed in the laboratory. Both came into being in a manner quite typical of industrial research. That is, they were not due primarily to direct attack for the need, but to discovery through observation. Many such discoveries come through experimental work which could scarcely be produced by deliberation.

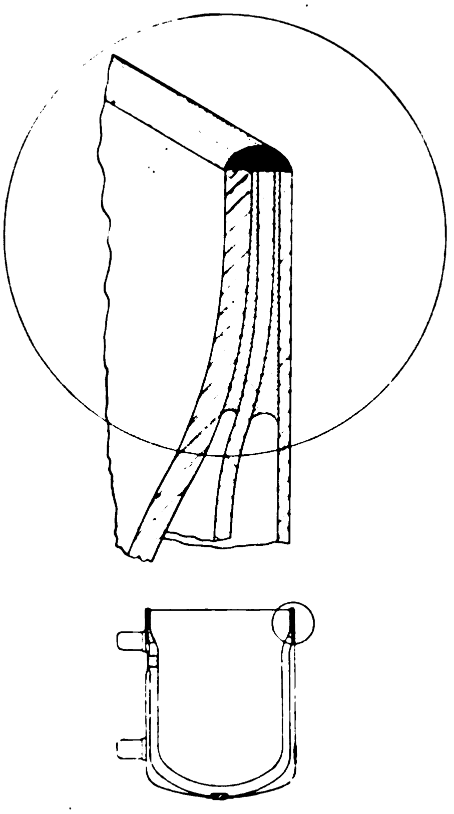


Fig. 1. Sectional Drawing and Detail of Welded Joint on an Electric Refrigerator

At the time these two items were recognized, recorded, and used for minor purposes, they had not been needed technically. When they were needed for their particular present service, they were already available and tested. They remind one of things available in books or libraries, but the comparison is only fair when the library becomes the entire unknown.

I refer in this case to the hydrogen-copper brazing and the atomic-hydrogen arc welding, both of which are used in the refrigerator.

Years ago, when we were making our first squirted tungsten filaments, we used to preheat them on iron gauze boats in hydrogen gas. One of the research men once attached a copper wire to one of these boats, although iron wire had been previously used for withdrawing it from the furnace. In this case the copper melted. This was not interesting, nor surprising, as the temperature was above the melting point of copper. But there was a very peculiar effect in this case. The wires of the gauze boat were now bright with a clean coating of copper which had spread with remarkable ease for long distances along the individual iron wires. This peculiarity was then tested for its possibilities, and it was found easy to copperplate large iron surfaces by very small quantities of copper, because it spread so easily. This led Dr. Coolidge to use the copper as a means of sticking together various metals, such as tungsten and iron, for the copper penetrates the capillary openings. This was then developed by Messrs. Palmer and Steenstrup into a commercial process for steel brazing which was easily applied to turbine labyrinths and steam plates, and finally to the refrigerator.

But copper brazing alone would not be good enough for surfaces over which enamel is spread. Such surfaces should be homogeneous. Copper is only part of the evaporator seal just described. Atomic-hydrogen welding is the other part.

As the copper brazing came from the old filament process, so the atomic welding came from the vacuum lamp. Dr. Langmuir studied certain reactions which took place on the inside walls of blackened lamps and connected these in his mind with the decomposition of traces of water vapor which came into the vacuum from the glass. Briefly put, this work led to the assumption that hydrogen atoms, as distinct from molecules, were exceedingly active. They could be produced in the electric arc—they could raise the temperature of metals exceedingly high, even to the melting point of tungsten itself. This led to the study of arc welding of metals by use of tungsten electrodes within a hydrogen atmosphere, and hence to atomic welding torches. It was found that the difficulties of ordinary electric welding, due to the occasional inclusion of slag or oxide within the welding joint, were thus removed, and the finished surface of the joint thus became suitable for enameling.

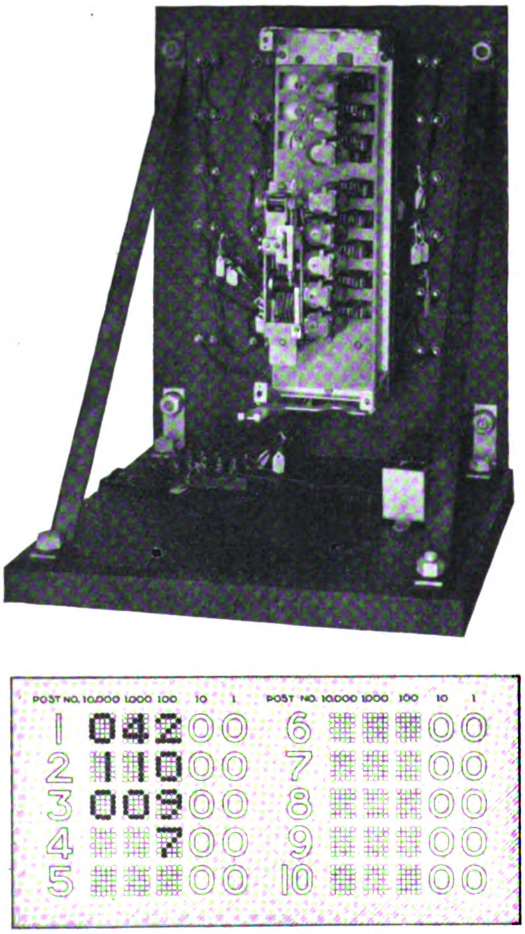
These two processes work out wonderfully well in such cases as our refrigerating unit, where any possibility of a leak must be removed. To me this is not quite so interesting because of the technical development as it is academically, for it brings Coolidge and Langmuir usefully together, where they never thought of going, and gives us another illustration of the value of constructive research.

Automatic Totalizing Possible with New Electric Equipment

Automatic indication of totals of various accumulating quantities is now possible with the use of recently-perfected electric equipment. This equipment, originally designed for the totalization of electric power demand originating in a large number of sources, can be applied to the quick and accurate totalling of units of several different numerical values.

The totals involved may be indicated in several places, either by means of large or small indicators. A typical application might cover the sale of tickets having different monetary values, from perhaps 50 different ticket windows. Whether the sales occur successively or simultaneously, the totalizing equipment will function and correctly total all sales.

Such a ticket totalling equipment has been designed and built, and involves the use of a motor-driven ticket machine. A key is depressed in the usual manner to issue a ticket of specified value. This starts the motor which runs until the ticket is cut off and ejected through an opening in the top face plate of the machine. During this operation, an electric circuit to the totalizing machine is momentarily interrupted. Each key is associated with two registers of the Veeder counter type, one registering continuously while the other can be reset to conform with the serial number of tickets issued.


POST NO. 10,000 1,000 100 10 1
POST NO. 10,000 1,000 100 10 1
1 04200
2 11000
3 00900
4 700
5 00
6 00
7 00
8 00
9 00
10 00
Selecting Device and Typical Board of Light Bulbs

An impulse collecting device responds to the ticket machine operation and functions to place an impulse in the totalizing device. The impulse is registered in the totalizing device with a definite numerical value equivalent to the ticket value.

Indication of the totals can be made on small indoor-type indicators, for totalizing in various numerical units. Indication may also be given on large, billboard-type signs, where numerals are formed by electric light bulbs.

Among the many possible uses for this equipment are the application to turnstiles in fair grounds, in subways and other places where it is desired to count and indicate the attendance totals, and also, in connection with the photo-electric tube, for indicating the total number of vehicles passing given locations, similar to the present application in the Holland Tunnel, but involving a number of counting points.

Beat-frequency Oscillators

Fields of Application—Principles of Operation—Requirements—Portable-type Oscillators—Laboratory-type Oscillators—Design of Condenser Plates

By **M. S. MEAD, JR.**
General Engineering Laboratory, General Electric Company

WITHIN the space of a few years the beat-frequency oscillator has become a very important piece of laboratory apparatus. The function of this type of oscillator is to deliver a pure sine wave of voltage, the frequency of which can be varied continuously over the audible range with the amplitude of the output remaining constant. The audible range of frequencies is generally considered to lie between 16 and the neighborhood of 14,000 cycles per second. However, the part of major importance as far as the ear is concerned lies between 60 and 6000 cycles per second. There are several factors which govern the choice of frequency range for a particular oscillator so that oscillators have different ranges depending on the uses for which they are designed.

The instrument was first developed for use in connection with the art of recording and reproducing sound. It is now recognized that the fidelity of any system used for speech or music depends largely upon its ability to transmit all of the component frequencies equally well; and therefore the action of the system can be tested by using pure, or single-frequency tones supplied from a beat-frequency oscillator. For instance, a vacuum-tube amplifier is to be tested to determine how it amplifies the various frequencies throughout the audible range. A small signal is impressed across the grid of the first tube by means of the beat-frequency oscillator. This input voltage is maintained constant as the oscillator frequency is varied and the output voltage from the amplifier is read, using either thermocouple or vacuum-tube voltmeters. The graph of the ratio of output to input is called a frequency characteristic. The ideal usually sought for is that this characteristic be a straight line parallel to the abscissa similar to the case shown in Fig. 1, the only difference being that the output is there plotted as a voltage rather than as a ratio. Aside from the sound recording and reproducing fields many uses for beat-frequency oscillators exist. Its calibrated scale covering the audio-frequency range makes the oscillator a convenient frequency standard. For instance, in calibrating quartz crystals, the crystal frequency is determined by measuring the frequency of the beat note between the crystal oscillator and the standard frequency which is available in steps of 10,000 cycles. In measurements of inductance, capacity, and power-factor by means of bridges there is needed a pure-tone-frequency source. Sometimes a measurement at 1000 cycles only is sufficient, but many times measurements are desired throughout the audio range. The oscillator is useful in calibrating various instruments such as vacuum-tube voltmeters. It is also used in audio transformer testing and more generally in tests on various kinds of transformer steel. Another application is in the adjustment and tests of resonant shunts which are to be placed in power lines to reduce certain prominent harmonics which interfere with telephone communication.

The beat-frequency oscillator makes use of two separate radio-frequency oscillators, one of which operates at a fixed frequency and the other at a variable frequency controlled by the operator. The difference in frequency between the two oscillators is made equal to the desired audio frequency, so that when the two radio-frequency oscillator outputs are combined and fed into a detector, the phenomenon known as "beat" occurs. This is similar to what is heard when two pure tones of slightly different pitch are sounded together. There is a sensation of beats coming with a frequency equal to the difference between the frequencies of the two sound waves. It is caused by an alternate in-phase and out-of-phase combination of the two sounds which periodically reinforce and destroy each other. In the beat-frequency oscillator this beat note is acted on by a vacuum-tube detector which subtracts the radio-frequency components and leaves the envelope of the interacting radio frequencies. The detector output, ordinarily from 0.1 to 1 volt of audio frequency, may then be amplified by any desired amount.

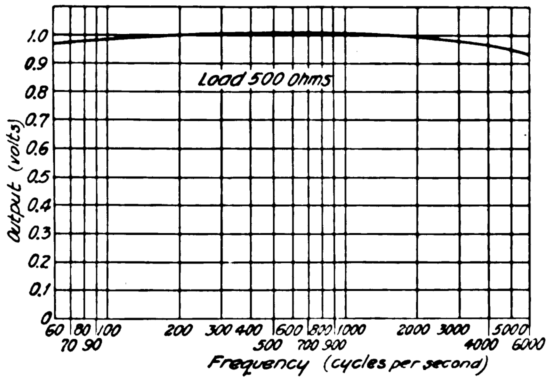


Fig. 1. Output Voltage Characteristic of a Portable-type Beat-frequency Oscillator Operating Into a 500-ohm Load

It is to be noted that the frequency variation necessary in the controlled radio oscillator is small relative to its maximum frequency. The frequency is controlled by a single variable condenser in shunt with a larger fixed condenser. For instance, with a fixed oscillator frequency of 100,000 cycles per second and a desired audio frequency of 50 to 10,000 cycles per second the controlled radio-frequency oscillator would have to be varied from 90,000 to 99,950 cycles per second or approximately 10 per cent of its maximum frequency.

Beat-frequency oscillators must meet several definite requirements in order to be of the greatest degree of usefulness. The output wave shape should be a pure sinusoidal function of time. The output voltage on a constant-impedance load should not vary over the frequency range. There should be a minimum of frequency drift with changes in temperature and battery voltage. Drift is understood to refer to slow changes in audio frequency, not produced by the operator, but due to changes in frequency of either radio-frequency oscillator. The control dial should permit accurate and convenient setting of the frequency. There should be no radio frequency present in the output circuit.

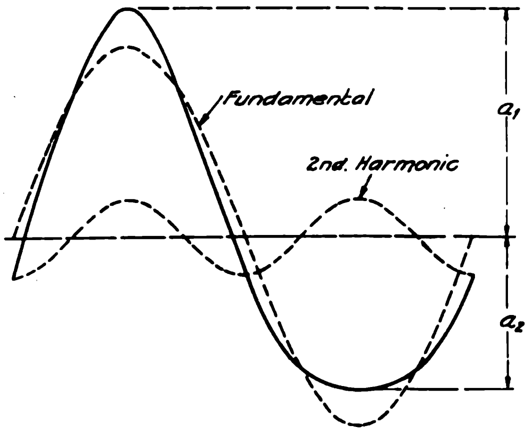


Fig. 2. A Plot of Wave Forms Showing Even-harmonic Distortion

Wave-shape distortion in beat-frequency oscillators may arise from several causes, including poor audio amplification, bad detection, and intercoupling between the two radio-frequency oscillators. Poor audio-frequency amplification may introduce both odd and even harmonics. The odd-harmonic distortion usually comes from the transformers if they are not large enough to handle the audio voltages impressed on them. The even-harmonic distortion may be caused by not operating the tubes on the proper part of their characteristic, particularly the output stage. If the latter is push-pull, the even-harmonic distortion in it is of course largely eliminated. The best form of detection for beat-frequency oscillators seems to be that known commonly as bias or plate-curvature detection. If the detector tube is operated on the part of its curve where the plate current is proportional to the square of the input voltage, the result of impressing the two radio-frequency voltages on the grid will be a current flowing in the plate circuit proportional to the product of the two radio-frequency voltages and with a frequency equal to their frequency difference. Radio-frequency components which occur are removed by filtering. A departure from proper detecting conditions appears to produce a special case of even-harmonic distortion, where one-half of the wave is of greater amplitude than the other half, as shown in Fig. 2. The third cause of distortion is inter-coupling between radio oscillators. This distortion becomes worse with lower frequency and seems to be largely odd-harmonic, as indicated in Fig. 3. Experience has shown that by operating the two radio-frequency oscillators in combination with two separate radio-frequency amplifiers and providing good electrical shielding between them this effect can be almost eliminated.

Where the number of vacuum tubes has to be kept to a minimum, another method of coupling may be used. This scheme uses a resistance-type Wheatstone bridge with equal ratio arms. Each oscillator output is connected to opposite points on the bridge and the detector is connected across only one arm. Thus the outputs are combined for the detector, but mutual coupling is prevented. This works readily on frequencies down to about 50 cycles per second; but below this frequency it is more difficult to secure good wave shape with this scheme.

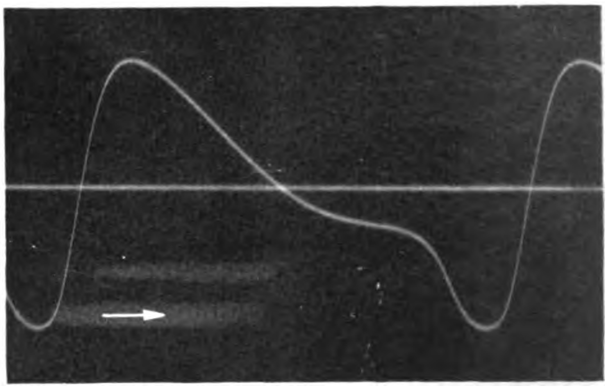


Fig. 3. An Oscillogram Showing Wave-shape Distortion Due to Radio-frequency Coupling

In testing for wave distortion and determining the degree of harmonic content, several methods are available. Oscillograms may be taken and analyzed, although much can be learned simply by inspecting the wave on the rotating mirror without photographing it. The presence of odd-harmonic distortion is usually immediately apparent because the kind that may occur as the result of either oscillator coupling, or the transformers taking too much exciting current. produces unsymmetrical positive halves of the wave and unsymmetrical negative halves. These may of course be caused by in-phase even harmonics, but they have not been encountered so far in this work. If odd-harmonic distortion is present, not much can be told about the even harmonics by inspection. However, if the odd harmonics are eliminated it is found that in most cases the remaining even-harmonic distortion consists largely of a second harmonic which appears as in Fig. 2. One-half of the wave is greater than the other half, but both halves are symmetrical about their central axis. In this case the distortion can be expressed quantitatively as

$$\text{Per cent harmonic} = \frac{(a_1 - a_2)\ 100}{a_1 + a_2}$$

where

a_1 = maximum positive ordinate
a_2 = maximum negative ordinate

Under these conditions the harmonics can be measured by taking direct and reversed readings with a peak-reading tube voltmeter. One other means of observing distortion is the low-voltage cathode-ray oscillograph in connection with another oscillator whose wave is known to be pure. Distortion can be interpreted through the well-known Lissajous figure effect. This method is equally effective at any audio frequency.

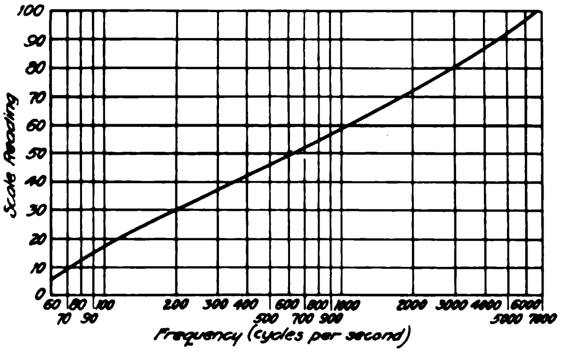
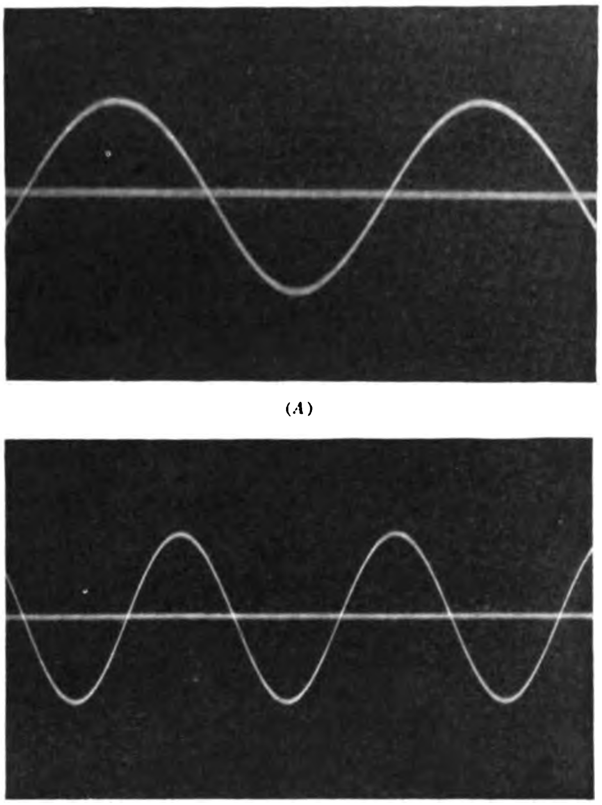


Fig. 4. Calibration Curve for a Portable Beat-frequency Oscillator

The problem of securing constant output voltage is the same as in any detecting and amplifying system. It will be seen that the detector input voltage remains constant, since the change in radio-frequency voltage is negligible as the radio frequency is varied, and the coupling to the oscillators is aperiodic. Using plate-curvature rectification does away with any grid-leak and condenser-frequency characteristic present in grid-circuit rectification. Transformers, where used, do not have any d-c. component of flux in their cores and possess low leakage reactance. In the resistance-capacity-coupled stages, tubes with an amplification constant of eight together with large coupling condensers and fairly low values of plate-circuit resistance give uniform amplification from 30 to over 10,000 cycles per second.

In order to secure accurate results with the oscillator, the frequency of the output should correspond with the dial setting or its calibration. When the oscillator is first set into operation the frequency may not correspond exactly to the scale marking because of minor changes which may occur in one of the radio oscillators. Several methods may be used to check the frequency at one point on the scale and a small adjustable condenser on the variable oscillator is set to bring the frequency to the correct value. In one method a note from a 384-cycle tuning fork is compared by ear with the oscillator operating a loudspeaker or headphones. The oscillator can readily be set to practically zero beat. Sixty-cycle power in many places is a good frequency standard. In this case the 60-cycle note from the power line is introduced in series with the oscillator output and headphones. A very convenient frequency standard is being used which consists of a single vibrating reed tuned to 60 cycles and operated electro-magnetically directly from the oscillator. The frequency can be set easily to within one-half cycle per second by this means. Checking the scale at one point insures that the rest of the scale is correct. However, if the frequency "drifts" or changes slowly, the calibration will be wrong by the number of cycles of drift. The percentage error is thus inversely proportional to the frequency at which the beat oscillator is set. These frequency changes are due to several causes, the most important of which are changes in battery voltage and changes in temperature which change the constants of the radio oscillators. By properly selecting the tubes, both radio oscillators can be made to drift the same amount on voltage changes so that the net effect is zero. Where the fixed oscillator is cyrstal-controlled, as in the portable oscillator to be described, battery voltage changes do affect the drift more than in the other type; but the



(A)

(B)

Fig. 5. Oscillograms Showing Wave Forms of One-volt Output at 60 Cycles and 100 Cycles

filament voltage can easily be maintained by rheostat control and the "B" batteries hold constant over their useful life, so that frequency change from this source is not troublesome. The greatest difficulty comes from changes in condenser capacity with temperature. Fixed air condensers are quite free from this difficulty, but many types of fixed condensers with mica dielectric suffer large changes in capacity with changes in temperature. Moulded condensers seem to be the worst offenders in this respect. A fixed mica condenser was found, however, which has a small temperature coefficient and is used where there is not room enough for air-spaced condensers.

In most work it is desirable to be able to set the oscillator frequency with the same precision at any frequency. This requires a variable condenser on the radio oscillator giving a frequency variation the logarithm of which is proportional to the rotor angle. Then the frequency versus dial setting is a sloping straight line when plotted on semi-logarithmic paper as in Fig. 4. This is the calibration curve of a beat-frequency oscillator. In this case one per cent change in angle gives a three per cent change in frequency at any point of the scale. This type of frequency adjustment also permits the attaching of a drum to the oscillator for automatically recording apparatus characteristics directly on semi-logarithmic paper. The development of the formula for the shape of plates in such a condenser is of interest and is given in the Appendix.

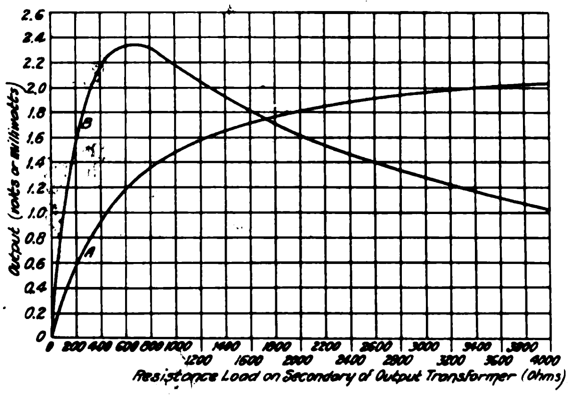


Fig. 6. Output Characteristics of a Portable Beat-frequency Oscillator

Curve *A:* Load-voltage characteristic
Curve *B:* Load-power characteristic

Radio frequency in the output is obviously undesirable. It may be eliminated by shielding and filtering. A single filter in the plate circuit of the detector is ordinarily sufficient. The constants of the filter should be so chosen that the audio-frequency characteristic is not affected by it. The presence of radio frequency in the output is best detected by connecting a tube voltmeter across the output and adjusting the beat frequency to zero. The tube voltmeter will then read whatever radio frequency is present.

Two models of beat-frequency oscillators have been developed involving the general principles which have been presented. A description of the two follows.

Portable Beat-frequency Oscillator(1)

The desirability of having a small portable beat-frequency oscillator arose on account of the development of so much field work in sound recording and radio broadcasting. The best method known to make a quick check upon the performance of recording or reproducing equipment is to take a frequency characteristic. The small oscillator to be described was developed with this purpose in mind.

The frequency range of this oscillator is from 60 to 6000 cycles over which it delivers one-volt output into a 500-ohm load with a maximum variation in voltage of 5 per cent over the frequency range. This curve is shown in Fig. 1. The wave shape is sinusoidal to within three per cent over this range. Fig. 5 shows the output wave shape at low frequencies. The amount of radio frequency in the output is less than one per cent. The output circuit is so arranged that it can operate into a load of from 50 ohms up to 2000 or more but delivers its maximum power of two milliwatts at 500 ohms and one volt. Fig. 6 shows how the output voltage and power vary with the load. By cutting in an attenuator potentiometer and holding one volt across the attenuator the output voltage can be set accurately in steps down to one millivolt. In using this feature it is necessary to feed into a high-impedance load for greatest accuracy.

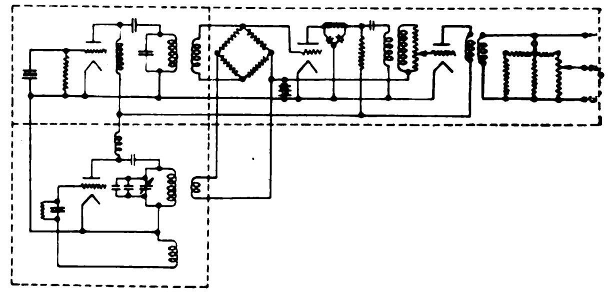


Fig. 7. Diagram of Connections for a Portable Beat-frequency Oscillator

As the detector operates on plate curvature no grid leak nor condenser is used. The radio-frequency filter of series inductance and shunt capacity are shown next to the detector plate in the circuit diagram (Fig. 7). Direct current is kept out of the interstage transformer primary by feeding the tube through a resistance and coupling the transformer through a blocking condenser. The detector gives about 0.3 volt output to the grid of the final tube. A potentiometer volume control across the secondary of the interstage transformer allows the output to be adjusted smoothly from zero to maximum. The output transformer has the magnetizing effect of plate current bucked out by a third winding not shown, carrying the filament current of the four tubes. The attenuator is of the constant-impedance type, so that no matter where it is set the load on the oscillator remains constant.

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(1) Identified by the trade designation "Type RY-21."

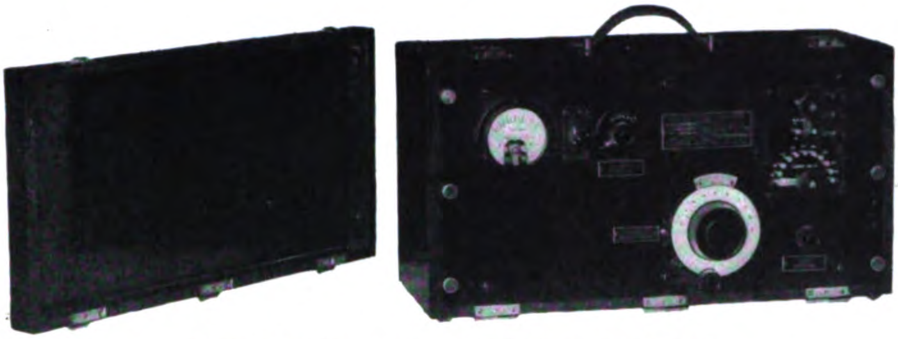

Fig. 8. Front View of the Portable Beat-frequency Oscillator

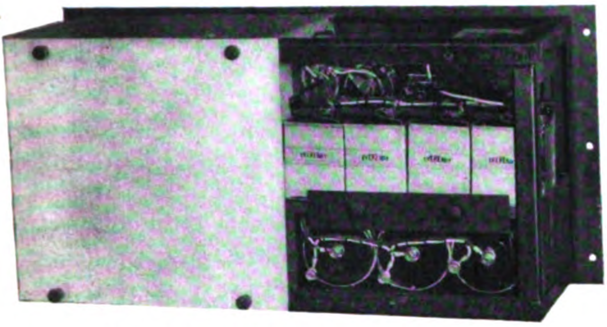

Fig. 9. Rear View of Beat-frequency Oscillator Removed from Case

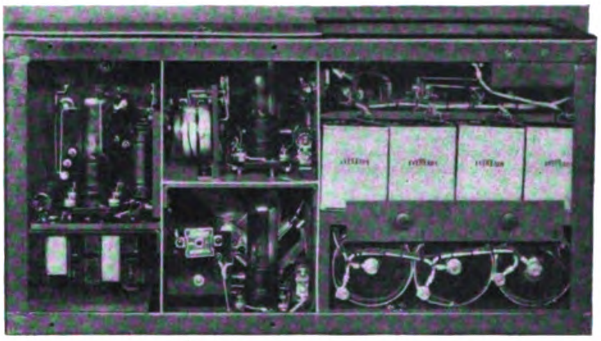

Fig. 10. Rear View of Beat-frequency Oscillator After Removal of Back Shield

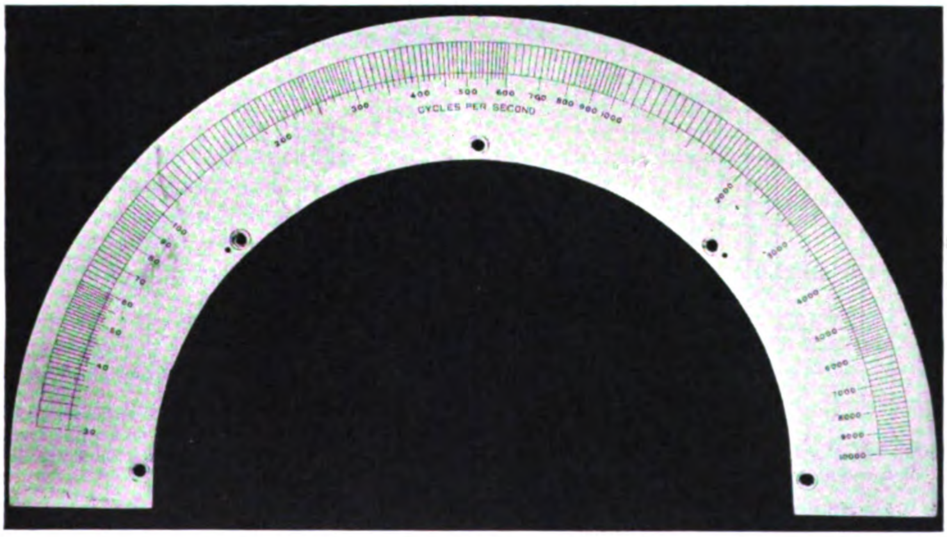

Fig. 11. Dial of Laboratory-type Oscillator Showing Scale of Frequency from 30 to 10,000 Cycles Per Second

The frequency is controlled by a four-inch dial graduated in 100 divisions. This has a vernier allowing the dial to be read to one-tenth of a division. Tests have shown that with a calibration curve such as is shown in Fig. 4 the frequency can be set with a precision of better than two per cent. A tabulated calibration gives greater precision than this, although two per cent accuracy is probably more than will ever be required from such an instrument. The frequency-adjusting condenser is operated by a screw driver and is located next to the control dial. The frequency range covers that part which is most important from the standpoint of audibility. At the present time an extension of the frequency range would require additional weight and space which would not be justified by the advantage gained.

Four PT-199 tubes are used, one as a fixed radio-frequency oscillator, one as a variable radio-frequency oscillator, one as a detector, and one as an audio-frequency amplifier or output tube. All of the tubes are operated from a common plate battery of 90 volts and a dry-cell filament battery of 4.5 volts. The detector and amplifier have in common a 4.5-volt "C" battery. The batteries give about sixty hours of operation.

A crystal-controlled oscillator of 100 kilocycles is used as a fixed oscillator. This stage is very stable since the crystal is operated at a small output compared to the usual practice with quartz crystals. The variable oscillator uses a variable condenser with the rotor plates shaped as already described. Conventional circuits as shown in Fig. 7 are used in both oscillators. This oscillator uses the bridge coupling of the two radio oscillators to the detector; and no intercoupling between oscillators is noticeable down to 60 cycles per second.

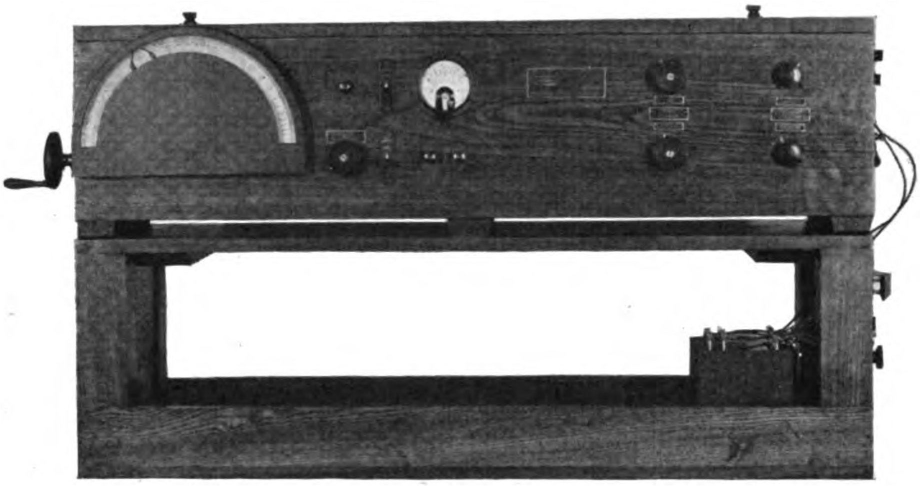

Fig. 12. Front View of the Laboratory-type Beat-frequency Oscillator

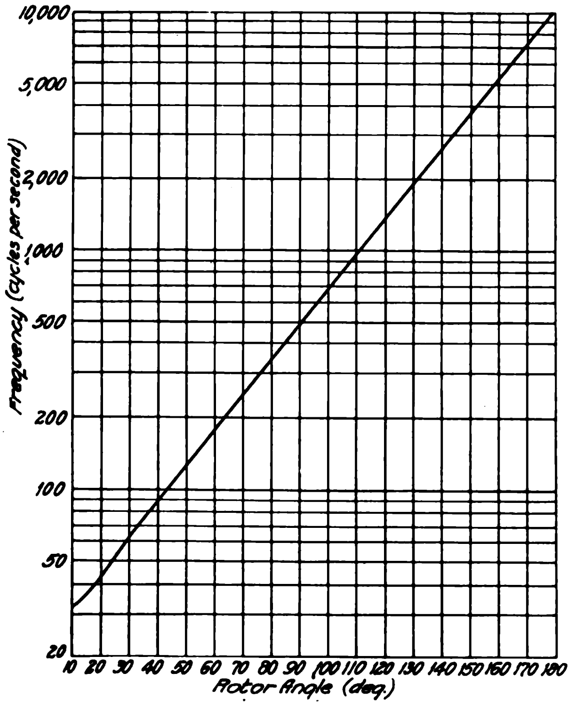

Fig. 13. Scale Characteristics for Laboratory-type Beat-frequency Oscillator

The oscillator weighs 44 lb. complete in its case and the external dimensions are 21 in. by 11 in. by 9 in. Its construction is clearly shown in Figs. 8, 9, and 10.

Laboratory Beat-frequency Oscillator[2]

The development of this oscillator for laboratory use has placed in the hands of laboratory workers a tool so useful as to be practically indispensable. This usefulness is due not only to the fact that there is a great need for just such a generator, but also because it fills the requirements so adequately. In the design of the oscillator it was realized that rugged construction of parts subject to wear would be quite essential if permanency in calibration was to be obtained. The first oscillator of this type has now been in service for three years and the scale indications between 30 and 10,000 cycles are still correct within 3½ per cent.

Before the oscillator is described the rating and performance should first be stated: *viz.*, it is designed to deliver an output of eight watts maximum undistorted power over a frequency range from 30 to 10,000 cycles. The frequency is direct-reading by means of a dial and pointer, as shown in Figs. 11 and 12. The accuracy of the scale (frequency versus rotor angle) is shown in Fig. 13, and the output characteristics in Fig. 14. The latter gives the output characteristics of one transformer tap. A switch cuts in another 6000 cycles which is added to the scale reading thereby extending the range to 16,000 cycles when

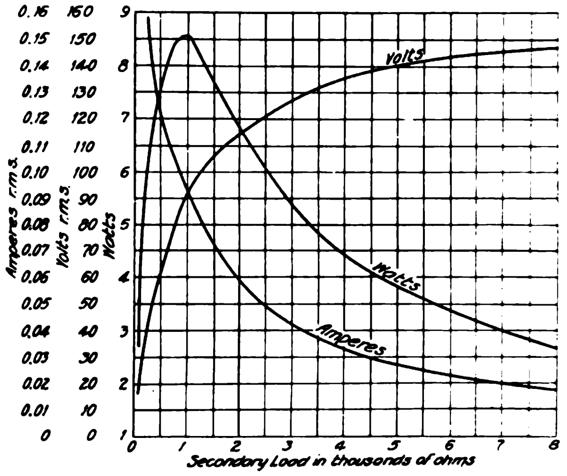

Fig. 14. Output Characteristics for Laboratory-type Oscillator from Tests Made at 1000 Cycles with an Output Transformer Having 3000 Turns Primary and 1500 Turns Secondary

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(2) Identified by the trade designation "Type RY-3."

desired. Fig. 15 shows the output voltage variation with frequency. It varies at most about 7 per cent from 30 to 16,000 cycles per second on a constant resistance load. The wave form (Figs. 16 and 17) is practically sinusoidal over the whole frequency range.

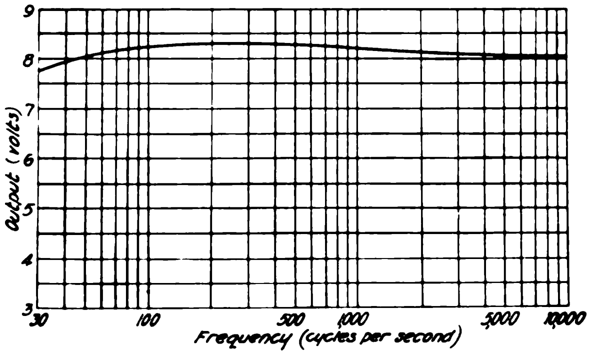

Fig. 15. Output Voltage Curves for a Laboratory-type Beat-frequency Oscillator

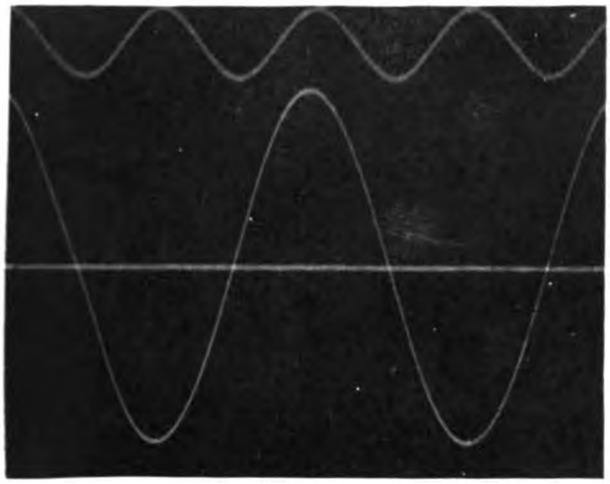

Fig. 16. Oscillogram of a 16-cycle Voltage Wave Measured Across Transformer Primary

As has been mentioned before, the wave form tends to become worse at low frequencies owing to intercoupling between the radio-frequency oscillators; but in this apparatus this effect is not apparent as low as 16 cycles per second. Furthermore, the wave form remains the same up to the maximum power output available. The frequency drift after the first few minutes of operation is negligible. The oscillators are commonly run several hours at a time without readjustment of the frequency.

The electrical arrangement of the oscillator is primarily standard. The fixed oscillator operates at 120 kilocycles. Both the fixed and variable oscillators work into radio-frequency amplifiers after which their outputs are added and led to the detector. The detector operates by virtue of plate curvature and feeds its output into a resistance-coupled amplifier through a radio-frequency filter. The output stage of four PT-842 tubes (low-amplification-factor PT-210 type) connected in parallel push-pull operates into a transformer. This is the only one in the system, and has a tapped secondary for matching various impedance loads for maximum output. Eight PT-201-A tubes precede the power stage. The filaments require a six to eight-volt storage battery; and, for a plate supply, a small storage battery of 240 volts tapped at 140 volts is used. A potential of 360 volts is supplied to the last stage when maximum power output is required. Bias voltages of −9, −15, and −37 volts are supplied by dry cells. These oscillators have also been supplied with plate power throughout from vacuum-tube rectifiers and also from d-c. motor-generators. The gain controls, coarse and fine, permit smooth and continuous output variation from zero to maximum. Filament and plate voltages are checked using the meter on the front panel. A calibration curve is shown in Fig. 18.

The oscillator is thoroughly shielded. The box is copper lined with several separate metal partitions; and the coils and fixed air condensers are in metal cans. Shielding is necessary to prevent coupling between the two radio-frequency oscillators and also to keep radio frequency out of the output. The interior view (Fig. 19) illustrates this feature as well as the disposition of the apparatus. The left front compartment houses the variable air condenser controlling the frequency. (This condenser is better shown in

Fig. 17. Oscillogram of a 30-cycle Voltage Output Wave from the Laboratory Oscillator Measured Across a Load of 500 Ohms

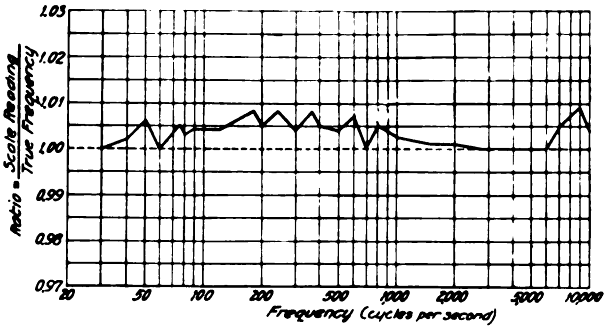

Fig. 18. Scale Calibration of a Laboratory-type Beat-frequency Oscillator

Fig. 20.) Behind is seen the variable oscillator with its radio-frequency amplifier. The coils are encased in brass cans. To the right, in a similar arrangement, is the fixed oscillator and its amplifier. Next is the radio-frequency filter and in front of that the detector tube in its own compartment. Next on the right come three tubes in the intermediate audio-frequency amplifier and finally the four tubes in the power stage. The frequency adjustment as seen next to the control dial consists of a midget variable condenser geared down to the adjusting knob so that a vernier control is secured. Similar means as described in connection with the portable oscillator are used to set the frequency at one point on the scale.

This oscillator weighs 160 lb. and the dimensions of the cabinet are 41 by 10½ by 13 inches.

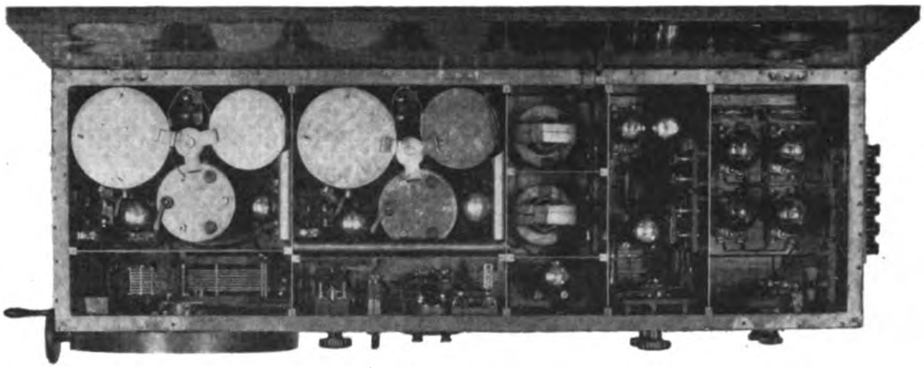

Fig. 19. Interior View of Laboratory-type Oscillator

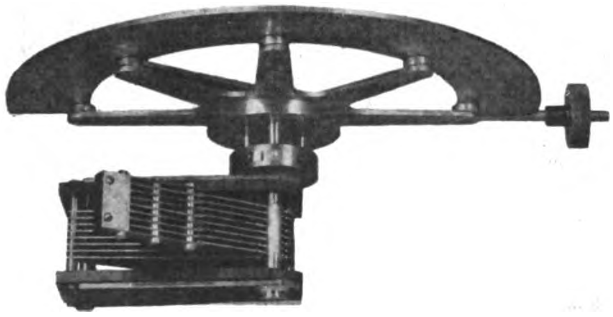

Fig. 20. The Condenser and Scale of a Laboratory-type Oscillator

APPENDIX

As an interesting corollary to the description of the beat-frequency oscillator, the design of the plates of the variable condenser used in this connection is here given.⁽³⁾

The desired relation between the audio frequency and the rotor angle is shown in Fig. 21. The slope of this curve is

$$m = \frac{\theta_2 - \theta_1}{\log_{10} f_2/f_1} = \frac{\theta_2 - \theta_1}{\log_{10} R}$$

where $f_2 = F_0 - f'_2$ and $f_1 = F_0 - f'_1$

Here f_1 = lowest audio frequency desired

f_2 = highest audio frequency desired

f_1' = maximum frequency of the variable oscillator

f_2' = minimum frequency of the variable oscillator

F_0 = the fixed radio frequency.

Maximum and minimum audio frequency occur for minimum and maximum radio frequency in the variable oscillator. In this way the audio frequency increases with increase in capacity of the controlling variable condenser. A certain capacity change produces a frequency change which is the same at any point of the scale. This simply means that the capacity accuracy required (in percentage) to produce a given frequency accuracy is fairly uniform under the method used, but with minimum audio frequency occurring at maximum capacity setting it would be very difficult to secure a good scale at the low-frequency end.

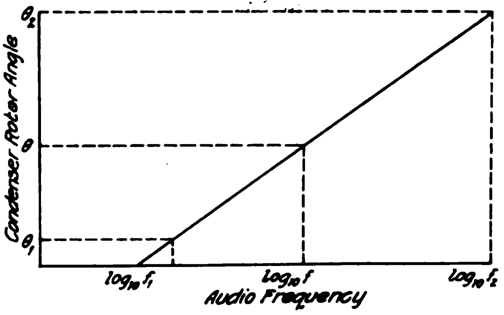

Fig. 21. Graph of Relationship Existing Between Frequency and Condenser Rotor Angle

It will be first established ⁽⁴⁾ how the capacity must vary as a function of the rotor angle in order to produce the desired frequency variation in the oscillator.

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(3) A derivation of this relationship was given also in an article, "Logarithmic Scale for Beat-frequency Oscillators," by E. R. Meissner, *I.R.E. Proceedings*, May, 1929, p. 879.

(4) Complete list of symbols used in the computations:

F_0 = Fixed radio frequency
f_1 = Minimum audio frequency
f_2 = Maximum audio frequency
f = Audio frequency
f' = Variable radio frequency
R = Ratio of maximum to minimum frequency f_2/f_1
θ_1 = Minimum rotor angle of condenser
θ_2 = Maximum rotor angle of condenser
θ = Rotor angle
f_1' = Variable radio frequency for audio frequency f_1
f_2' = Variable radio frequency for audio frequency f_2
C = Capacity of variable condenser at angle θ
C_0 = Capacity necessary to give frequency F_0 with inductance L
L = Inductance of oscillator coil
n = Number of air spaces in condenser
d = Spacing between stator and rotor plates
A = Area of rotor plate in square centimeters
k = $10^{11}/36\pi$
ρ = Radius of rotor plate at angle θ
r = Radius of cutout in stator plate.

The equation of the curve in Fig. 21 is:

$$\theta-\theta_1=m\ (\log_{10}f-\log_{10}f_1)$$

so that $f=f_1\ 10^{\left(\frac{\theta-\theta_1}{m}\right)}$

since $f=F_0-f',\ f'=F_0-f_1\ 10^{\left(\frac{\theta-\theta_1}{m}\right)}$

As f' is the frequency of the variable-radio-frequency oscillator, it is very nearly

$$f'=\frac{1}{2\pi\sqrt{LC}}$$

This gives us $C=\dfrac{\left[F_0-f_1\ 10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-2}}{4\pi^2L}$

$$=C_0\left[1-\frac{f_1}{F_0}10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-2}$$

where $C_0=\dfrac{1}{4\pi^2F_0^2L}$

Having the capacity we proceed to the area of condenser plate necessary:

Since $C=\dfrac{k\ An}{d}$

$$A=\frac{d\ C_0}{kn}\left[1-\frac{f_1}{F_0}10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-2}$$

The area under a polar curve (Fig. 22) subtracting a cutout of uniform radius r, is:

$$A=\tfrac{1}{2}\int(\rho^2-r^2)\,d\theta\quad\therefore\ \frac{dA}{d\theta}=\tfrac{1}{2}\,(\rho^2-r^2)$$

also $\dfrac{dA}{d\theta}=\dfrac{d}{d\theta}\left\{\dfrac{dC_0}{kn}\left[1-\dfrac{f_1}{F_0}\,10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-2}\right\}$

$$=\frac{2dC_0}{kn}\log_e 10\,\frac{f_1}{F_0}\,\frac{10^{\left(\frac{\theta-\theta_1}{m}\right)}}{m}\left[1-\frac{f_1}{F_0}\,10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-3}$$

Equating this to $\tfrac{1}{2}\,(\rho^2-r^2)$ gives for ρ

$$\rho=\sqrt{\frac{4dC_0}{kn}\log_e 10\,\frac{f_1}{F_0}\,\frac{10^{\left(\frac{\theta-\theta_1}{m}\right)}}{m}\left[1-\frac{f_1}{F_0}\,10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^{-3}+r^2}$$

This appears rather formidable for design purposes but it can be simplified considerably.

With a 180-deg. condenser scale, $\theta_1=0$ and $\theta_2=\pi$.

Then $m=\dfrac{\pi}{\log_{10}R}$ so when $\theta_2=\pi$, $\rho=\rho_{max}$ and we get:

$$\rho_{max}=\sqrt{\frac{4dC_0}{kn}\log_e 10\,\frac{f_2}{F_0}\,\frac{\log_{10}f_2/f_1}{\pi}\left[1-\frac{f_2}{F_0}\right]^{-3}+r^2}$$

This requires n to be

$$n=\frac{4dC_0\log_e 10f_1R\left[1-\frac{f_2}{F_0}\right]^{-3}}{km\ F_0\left[\rho_m^2-r^2\right]}$$

Substituting this back in the equation for ρ

$$\rho=\sqrt{\frac{(\rho_m^2-r^2)\ 10^{\left(\frac{\theta-\theta_1}{m}\right)}\left[1-\frac{f_2}{F_0}\right]^3}{R\left[1-\frac{f_1}{F_0}\ 10^{\left(\frac{\theta-\theta_1}{m}\right)}\right]^3}+r^2}$$

Since $10^{\left(\frac{\theta-\theta_1}{m}\right)}=R^{\frac{\theta-\theta_1}{\pi}}$

$$\rho=\sqrt{\frac{(\rho_m^2-r^2)\,R^{\left(\frac{\theta-\theta_1-\pi}{\pi}\right)}\left[1-\frac{f_2}{F_0}\right]^3}{\left[1-\frac{f_1}{F_0}R^{\left(\frac{\theta-\theta_1}{\pi}\right)}\right]^3}}$$

Since $(1-x)^3=(1-3x)$ when $x<<1$ and $\theta_1=0$

$$\rho=\sqrt{\frac{(\rho_m^2-r)\left[1-3\frac{f_2}{F_0}\right]}{\left[R^{1-\frac{\theta}{\pi}}-3\frac{f_2}{F_0}\right]}+r^2}$$

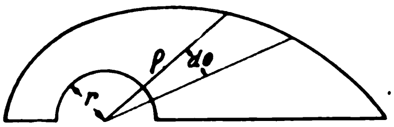

Fig. 22. Polar Plot, Showing Dimensions Involved in Computation of Condenser Plates

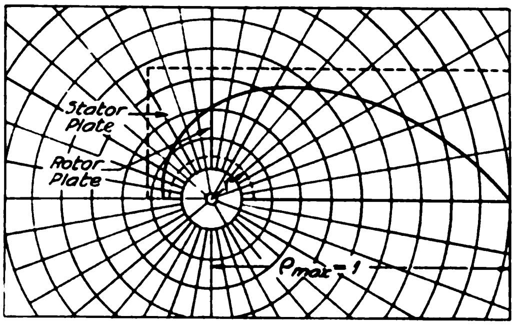

Fig. 23. The Polar Plot of the Configuration of a Condenser Plate

If the relative shape is desired

$$\frac{\rho}{\rho_m}=\sqrt{\frac{\left[1-\left(\frac{r}{\rho_m}\right)^2\right]\left[1-3\frac{f_2}{F_0}\right]}{\left[R^{1-\frac{\theta}{\pi}}-3\frac{f_2}{F_0}\right]}+\left(\frac{r}{\rho_m}\right)^2}$$

It is seen that the shape of the plates is a function of the maximum and minimum audio frequency desired, the fixed radio frequency, and the ratio of the cut-out radius to the maximum plate radius. In designing a condenser by this method it is well to cover the frequency range desired in 170 deg. rotation, leaving 5 deg. at either end of the scale since, because of edge effect, the end points of the scale tend to depart from the calculated values. The easiest way to do this is to use in place of the desired f_1 and f_2 in the preceding formulas

$$\text{new}\,f_1=\frac{175}{180}\,f_1\ \text{desired}$$

$$\text{new}\,f_2=\frac{185}{180}\,f_2\ \text{desired.}$$

In Fig. 23 is illustrated an example of plate shape for one oscillator.

Glyptal Mica Moves Ahead—Now the Flexible Form

By LAWRENCE E. BARRINGER
Engineer of Insulations, General Electric Company

THE superior properties of rigid mica insulation cemented or bonded with Glyptal were pointed out in a previous article.(1) Since the introduction of this form of pasted mica insulation, over one and a half million commutators have been constructed in this country and abroad using such mica for insulation in the form of segments, cones, and shells. These commutators have ranged in size from one inch to fifty-one inches in diameter and from one-half inch to fifteen inches in face or bar length.

Glyptal in a modified form has since been found also highly advantageous for the production of a flexible form of mica insulation.

While the chief use of pasted mica is in commutator insulation, requiring the material in rigid form, as for instance flat plates for segment insulation or molded forms as cones and shells, the construction of electrical apparatus often requires pasted sheet mica in flexible form as between the high-voltage and low-voltage coils of transformers, pads between core and coils of transformers, under the end windings of high-voltage railway armatures, at cross-overs and under terminals of field coils, pole insulation, to some extent as spool flange insulation, etc.

In all of these applications of flexible mica, the first requirement is that of a high degree of flexibility to admit of readily wrapping the mica around sharp bends or over irregular surfaces without loosening or displacement of the mica plates or flakes. In most instances, permanent flexibility is required as the mica insulation may not be supported at every point and the gradual development of brittleness from any cause may lead to a loosening of the mica flakes and an impairment of the insulation. For most applications it is undesirable and detrimental to have the bond of the mica loosened by varnish solvents or by mineral oils, as this will cause a loosening of the tightly-wound assembly. Most armature and field coils are dipped or brushed with insulating varnish containing such solvents as naphtha, toluol, benzol, etc., and of course many transformer coils are permanently immersed in light mineral oils.

Flexible mica insulation, therefore, should be highly flexible at the outset to facilitate winding operations, should remain permanently flexible so as not to become unserviceable in stock, should not crack, break, or flake off after being assembled, should not be affected by varnish solvents or mineral oils, and should retain its pliability and insulating value under the maximum temperature rise of electrical apparatus.

For the production of flexible pasted mica, a variety of pasting or bonding materials have heretofore been employed including spirit varnishes (containing castor oil or other ingredients to produce flexibility), asphaltic varnishes, and linseed-oil varnishes. Such materials have been generally satisfactory but in many instances the degree of flexibility decreases so rapidly that the material must be used within a comparatively short time after it is manufactured or it becomes too brittle for use. Other forms gradually become brittle after assembly, and some forms are readily attacked by mineral oils or solvents or do not withstand operating temperatures without impairment.

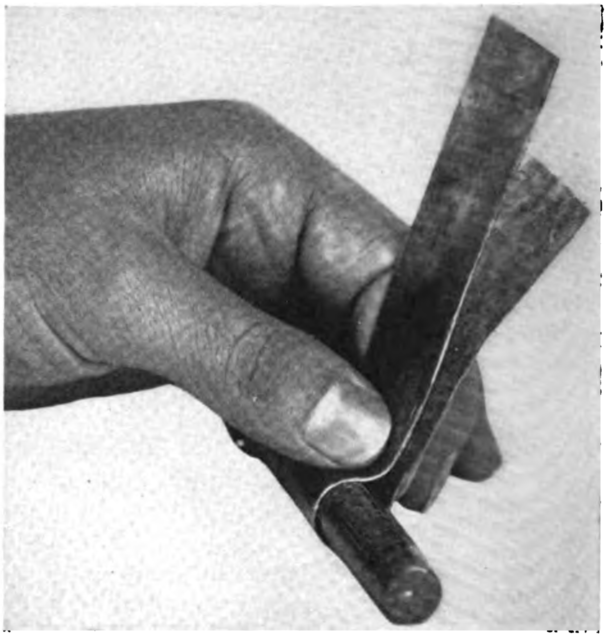

Fig. 1. An Illustration of the Flexibility of Glyptal-bonded Mica. (The sample here used was of the same dimensions as the test specimens referred to in the article.)

By modification of the Glyptal resin originally used for rigid insulation, it has been found possible to produce a high degree of flexibility which remains permanent under practically all conditions encountered in service. The unusual flexibility secured in this type of Glyptal-pasted mica is indicated in Fig. 1.

Varnish made with this flexible form of Glyptal is easily applied and requires no change in the manufacturing technique of producing flexible mica sheets.

In determining the relative value of Glyptal-bonded flexible mica, comparison was made with three other forms of flexible mica in commercial use. In this article the latter will be referred to as No. 1, No. 2, and No. 3, Glyptal being designated No. 4.

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(1) "A Revolutionary Development in Mica Insulation," by L. E. Barringer, GENERAL ELECTRIC REVIEW, Nov., 1926, p. 757.

The various specimens were prepared from sheets of 0.015-in. thickness and consisted of strips one inch wide by eight inches long. All specimens were cut from stock of recent manufacture.

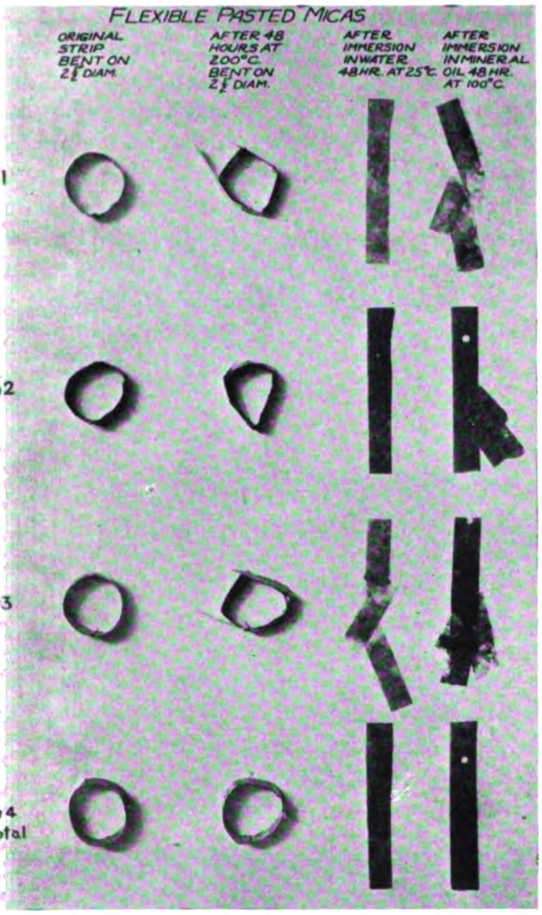
FLEXIBLE PASTED MICAS
ORIGINAL STRIP BENT ON 2½ DIAM.
AFTER 48 HOURS AT 200°C BENT ON 2½ DIAM.
AFTER IMMERSION IN WATER 48HR. AT 25°C
AFTER IMMERSION IN MINERAL OIL 48 HR. AT 100°C
No1
No2
No3
No4 Glyptal

Fig. 2. Graphic Chart Showing the Results of Physical Tests Applied to Three Earlier Types of Flexible Mica Insulating Material and to Glyptal-pasted Mica

The physical tests consisted of the following:

(*a*). Wrapping around a two and one-half inch mandrel some of the strips as received

(*b*). Wrapping around the two and one-half inch mandrel other strips which had been baked for 48 hr. at 200 deg. C.

(*c*). Immersing a third set of specimen strips for 48 hr. in water at 25 deg. C.

(*d*). Immersing the remaining specimens for 48 hr. in mineral oil at 100 deg. C.

The results of these tests are clearly indicated in Fig. 2.

The brittleness or breaking apart of the mica in most cases is clearly apparent.

A fifth test was made by baking strips 48 hr. at 200 deg. C. and then examining the condition of the binder with the following results:

Sample No. 1:	Binder quite brittle, mica separates quite readily
Sample No. 2:	Binder less plastic than original but has still fairly good adhesive property
Sample No. 3:	Binder very brittle, appears to have little adhesive property left
Sample No. 4: (*Glyptal*)	Binder still quite flexible with good adhesive property.

On the basis of an arbitrary rating value of 100 points for the best results in each test, Table I has been prepared to give approximate data of the relative values.

In addition to these physical tests, measurements of dielectric strength indicated that the values of Glyptal-pasted mica ranged from 17 to 25 per cent higher than those of the other micas. The dielectric constant and power-factor were approximately the same.

TABLE I

Property	MICA SAMPLE			
	No. 1	No. 2	No. 3	No. 4 (*Glyptal*)
Flexibility of original sheet	100	90	80	100
Flexibility after ageing (48 hr. at 200 deg. C.).....	60	70	50	90
Effect of water (48 hr. at 25 deg. C.)...............	90	90	50	100
Effect of mineral oil (48 hr. at 100 deg. C.).........	50	70	50	90
Effect of heat on binder (48 hr. at 200 deg. C.)......	60	70	50	90
Average.............	72	78	56	94

The flexible form of Glyptal-pasted mica is now in commercial use and has given practical evidence of its outstanding merits with respect to degree and permanence of flexibility, resistance to mineral oils or solvents, and dielectric value.

In addition to the use of flexible Glyptal mica in sheet or plate form, it is proving highly useful in the production of composite insulation, as for instance in the making of slot or cell insulations for direct-current motors by combining flexible Glyptal mica with sheet fiber and glassine paper. The slot insulation secured by this combination possesses more permanent flexibility and thus insures: (a) closer adherence to the coils with no springing back due to gradually developed brittleness, and (b) freedom from cracking or breaking in assembly, stock, or service as may occur with either the initially or finally brittle material characteristic of some of the pasted mica insulation made with solutions of natural gums and resins.

The Welding of Ferrous and Non-ferrous Metals by the Atomic-hydrogen Flame

Tungsten—Molybdenum—Cast Iron—Alloy Steels—Aluminum and Its Alloys—Brass—Nickel—The Equipment and Its Operation

By R. A. WEINMAN
Research Laboratory, General Electric Company

THE atomic-hydrogen flame possesses certain unique characteristics that make it an exceptionally useful tool for the welder. Compared with its predecessors, the oxy-hydrogen and oxy-acetylene flames, it has one feature in common: that the gas is fed into the flame in the molecular state, but there the similarity ends.

Upon entering the atomic-hydrogen welding flame, a portion of the gas is made to pass through an electric arc, the remainder merely serving to replenish the envelope of molecular hydrogen around the arc. The intense heat of the arc dissociates the molecules of the hydrogen passing through it, or in other words, it forcibly separates the two atoms that formed each molecule. This condition is elastic and the atoms have thus imparted to them a store of chemical energy equivalent to that which was necessary to pull them one from the other. Charged with this energy they travel to the comparatively cool zone beyond the arc, or to the metallic surfaces to be welded and there, combining to molecules again, they release as heat the atomic energy which they received from the arc. Therefore, in the atomic-hydrogen flame proper *no combustion takes place*, the action in effect being a chemical transmission of heat from a source to the place where it is to be utilized.

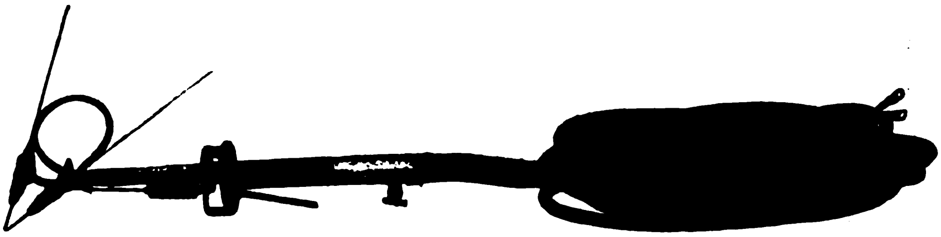

Fig. 1. Improved Model of Atomic-hydrogen Electrode Holder and Torch, with Leads and Hose

Combustion does of course take place when the molecules of hydrogen come into contact with the surrounding air, as in the final phase of combustion in the oxy-hydrogen flame. However, this envelope of burning gas is of but secondary consequence in either the atomic-hydrogen or the oxy-hydrogen welding processes. More detailed descriptions of the properties of the atomic-hydrogen flame and some of its early industrial applications have already appeared in the technical press.(1)

The latest model of the combined electrode holder and gas torch, with leads and hose, is illustrated in Fig. 1. It differs from the earlier models principally in being of simpler construction and capable of withstanding higher temperatures.

The shape of the atomic-hydrogen flame for a particular setting of the electrodes is shown in Fig. 2. The flame itself may be spread or diminished in size by altering the distance between the electrodes. This enables the operator to begin a weld with sufficient spread of heat to start the fusion of a comparatively heavy section and to gradually diminish the flame as the end of the weld is approached without changing the current.

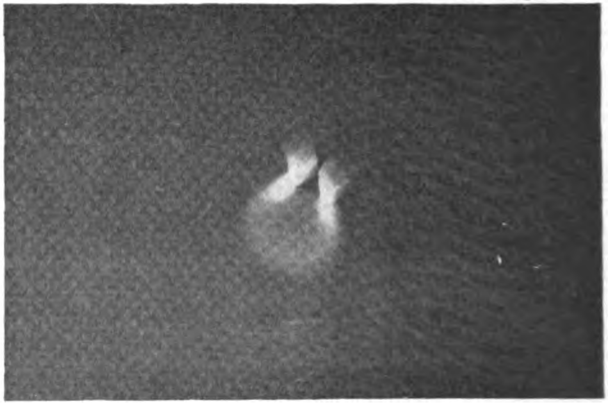

Fig. 2. Photograph of the Atomic-hydrogen Flame and the Tips of the Electrodes

For maximum heat with currents of 20 to 60 amp. and $\frac{1}{16}$ to $\frac{1}{8}$-in. electrodes, the electrode tips should be kept approximately $\frac{3}{16}$ to $\frac{1}{4}$ in. from the work and the diameter of the flame should be kept as near $\frac{1}{2}$ in. as possible. These conditions enable the operator to obtain excellent penetration with a narrow bead.

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(1) "Flames of Atomic Hydron," by Dr. Irving Langmuir, *Industrial and Engineering Chemistry*, June, 1927, p. 667.

"Atomic Hydrogen Arc Welding," by R. A. Weinman and Dr. Irving Langmuir, GENERAL ELECTRIC REVIEW, March, 1926, p. 160.

Application to Metals of High Melting Point

When in the form of thin sheets or rods, tungsten metal, which has a melting point of 3660 deg. K. or approximately 3390 deg. C. or 6130 deg. F., can be fused together with currents of 40 amp. or more. For welding tungsten rods of comparatively small diameter, say 10 to 20 millimeters, currents as low as 20 amp. in the arc circuits will suffice.

Tungsten and molybdenum oxidize very rapidly if they are not protected by the mantle of [molecular hydrogen from the torch when cooling from their fusion temperatures after welding.

The temperature used in the welding of these two metals produces a marked grain growth, similar to cast tungsten and molybdenum, in which state they have very little ductility. This limits the welding of these metals to objects which are not called upon to withstand excessive vibration. When other metals, such as low-carbon steel, nickel, or alloys of tungsten or molybdenum are used for filler rods, welds having sufficient ductility to withstand temperature changes and mechanical strains can be made. Molybdenum melts and flows like soft solder, but tungsten exhibits great viscosity even at this high temperature and flows sluggishly. In welding tungsten alone, it is best to use a filler rod of the same metal but of very small diameter. The edges of the heavier body to be welded are first heated until the surface fuses, after which the metal from the filler rod is added by puddling. When welding molybdenum or tungsten, all mechanical strains should first be removed either by forming the object hot in a reducing atmosphere or by forming the object cold so that no mechanical force is required to hold the edges in position for welding. This precaution is necessary to prevent cracking after the weld is complete.

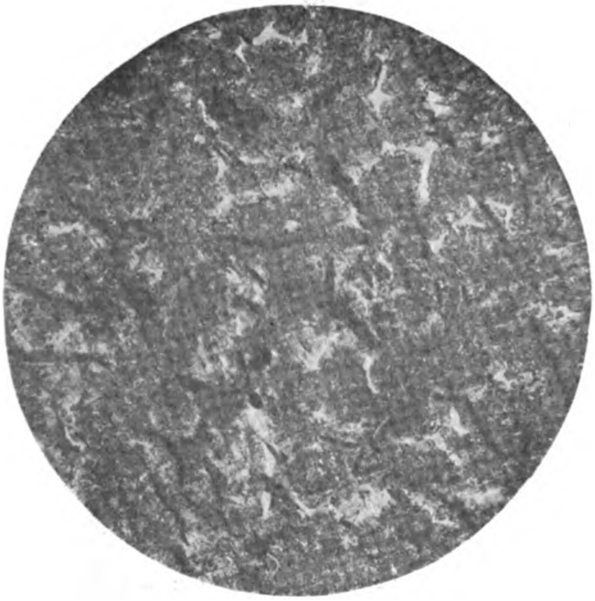


Fig. 3. Photomicrograph of Cast-iron Weld Metal
(Magnification 100 times)

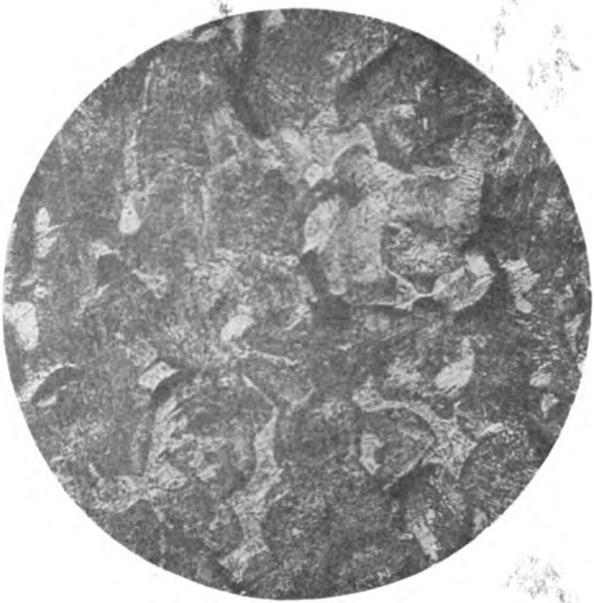


Fig. 4. Cast-iron Parent Metal
(Magnification 100 times)

Application to Metals of Lower Melting Point

Cast iron is very fluid when molten and therefore great care is required in building up a section when welding this metal. If too much of the metal is in a molten state at one time or too much is added at one time to a given area, there is liklihood of an overflow. The metal should also be made to freeze first at the bottom of the pool and solidify upward, otherwise the exposed areas will solidify first and cause shrinkage cavities in the interior. To do this, the atomic-hydrogen flame should be gradually drawn away from the surface of the molten pool. This procedure should be carried out even when small deposits of cast iron are being made on other metals. Fig. 3 shows the micro-structure of a weld made in an ordinary iron casting without preheating the casting. Fig. 4 shows the micro-structure of the parent metal of the same casting where not affected by the welding heat. A comparison of this photomicrograph with that in Fig. 3 indicates that the suspended graphite is more finely divided in the weld than it is in the parent metal. Broken sections of the two specimens also show a finer grain size in the welded section. Cast-iron filler rod containing 3½ per cent silicon and 3½ per cent carbon, or strips of the parent metal when obtainable, can be used as the filler rod. When neither can be obtained, small fragments of the parent metal held in tongs may be used for filler.

Bronze is applied to cast iron by wetting the surfaces of the edges with the atomic-hydrogen flame, adding the bronze in a molten state, and allowing it to coalesce to the surfaces.

Castings of different thicknesses or of very intricate shapes should be preheated if possible before welding. In many cases annealing the casting is sufficient to relieve the internal strains which would otherwise cause cracks after welding. If the casting is of a design where local strains cannot be compensated for by movement within the casting, the entire casting should be heated to a semiplastic condition before welding is started.

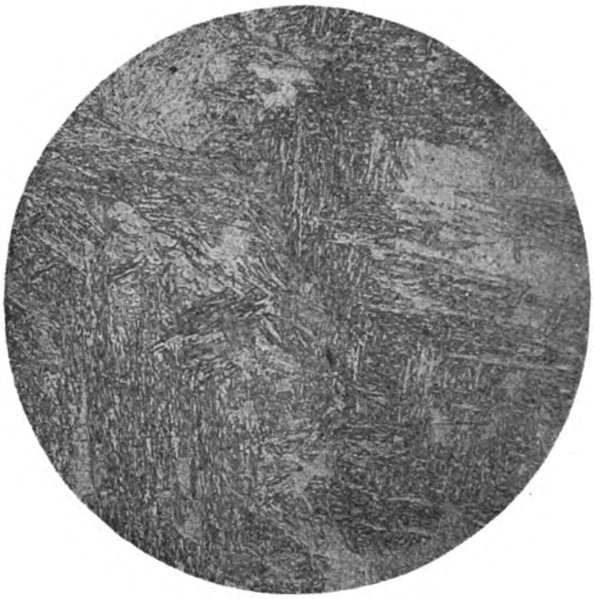


Fig. 5. Weld of Alloy Steel, 13 Per Cent Chrominum, 0.11 Per Cent Carbon
(Magnification 100 times)

Fig. 6. Weld of Alloy Steel, 13 Per Cent Chrominum, 0.30 Per Cent Carbon
(Magnification 100 times)

Chromium steels containing 13 per cent chromium and 2 per cent carbon are similar to cast iron in this respect. If a tool or a die made of such steel is to be welded, or if the steel is to be used as a cutting edge welded to a low-carbon steel shank, the weld should be made with the metal at approximately 750 to 780 deg. C. (1382 to 1437 deg. F.)

Steels containing chromium in appreciable amounts can as a rule be welded at room temperature provided the carbon content is not over 0.70 per cent. Figs. 5, 6, and 7 show micro-sections of 13 per cent chromium steel with 0.11, 0.30, and 0.70 per cent carbon. The welds were all made with the metal at room temperature. They were then annealed by soaking for three to four hours at 770 deg. C. (1420 deg. F.) and furnace-cooled for 18 hours to insure maximum ductility.

Tungsten steels containing up to 18 per cent tungsten and 0.6 per cent carbon have been welded cold after thoroughly annealing the specimen. Deposits of new metal are often applied to worn cutting edges of practically all steel alloys by the atomic-hydrogen flame, after which they are heat treated and machined as new metal.

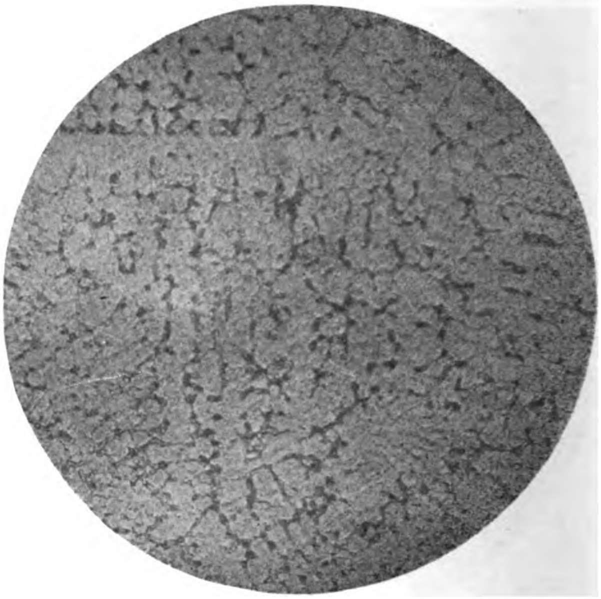
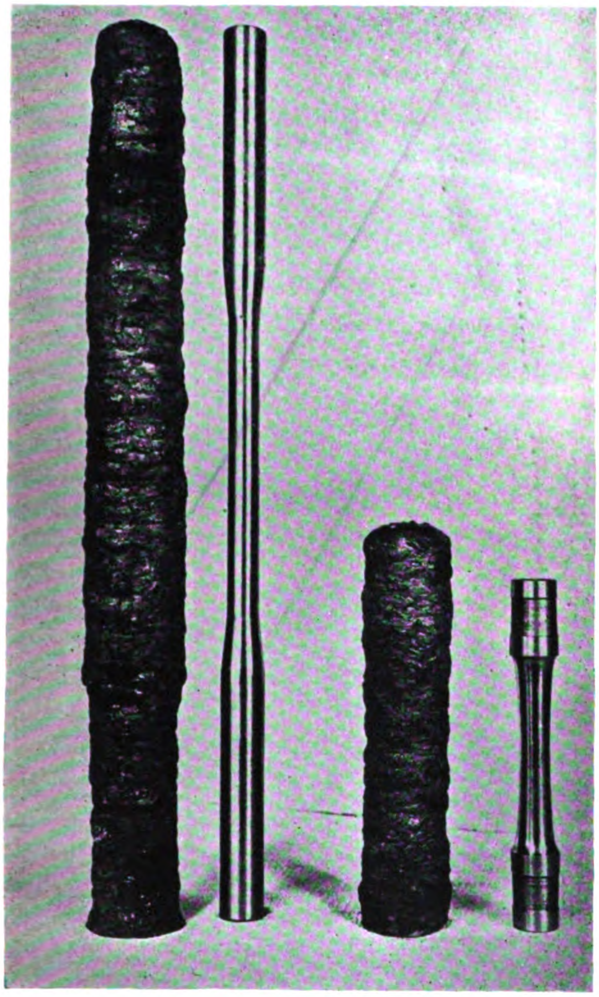


Fig. 7. Weld of Alloy Steel, 13 Per Cent Chrominum, 0.70 Per Cent Carbon
(Magnification 100 times)

High-carbon steels up to 1.25 per cent carbon content have been welded, using filler rods of the same content as the parent metal. The loss of carbon in the weld averaged 25 to 30 per cent, depending largely on the amount of metal deposited. The greatest loss of carbon in steel welds made with the atomic-hydrogen flame takes place in plain carbon steels. In the case of the chromium steel mentioned previously (13 per cent Cr and 2 per cent C), an analysis of the parent and welded metals showed no change in carbon content. This is also true for steels of the same chromium content but with as low as 0.11 per cent carbon, and of tungsten steels containing as much as 4 per cent tungsten.

Figs. 8 and 9 show built-up tension and fatigue tests specimens of all-weld metal made from a number of standard and special welding wires made expressly for the atomic-hydrogen welding process. The metal is built to a ¾-in. diameter rod for ⅜-in. specimens, the tension specimen being 10 in. long and the fatigue specimen 4 in. long.

Aluminum and aluminum alloys containing copper, zinc, silicon, and magnesium give solid homogeneous welds. Figs. 10 and 11 show both parent and deposited metal of commercial aluminum containing a large percentage of impurities, parent metal having been used for filler. The atomic-hydrogen flame will reduce aluminum oxide at 2080 deg. C. (3780 deg. F.) but as the metal melts at 630 deg. C. (1167 deg. F.) it is necessary to use a reducing agent or flux in addition to the reducing atmosphere of the hydrogen when welding thin sections of the metal. Edge welds can be made without the addition of filler rod by having the edges very close together and spreading over the surfaces to be joined a concentrated solution of the flux. Butt welds are best made with additional filler rod, either spreading the flux solution on the filler rod or directly on the surface to be welded. Top and corner welds are made in the same way with additional filler rod. The fluxes used for aluminum welding are the same as commonly used for other welding processes. The welding rod for aluminum and aluminum alloys should contain 3½ to 4 per cent silicon, where silicon in the deposited metal is not objectionable.



Figs. 8 and 9. Built-up Tension Specimen (at the left) and Built-up Fatigue Specimen (at the right) Before and After Machining for Test

Alloys of copper and aluminum with an excess of copper are treated like aluminum, except for the filler rod. When welding any special alloy, the filler rod should be of the same composition as the parent material.

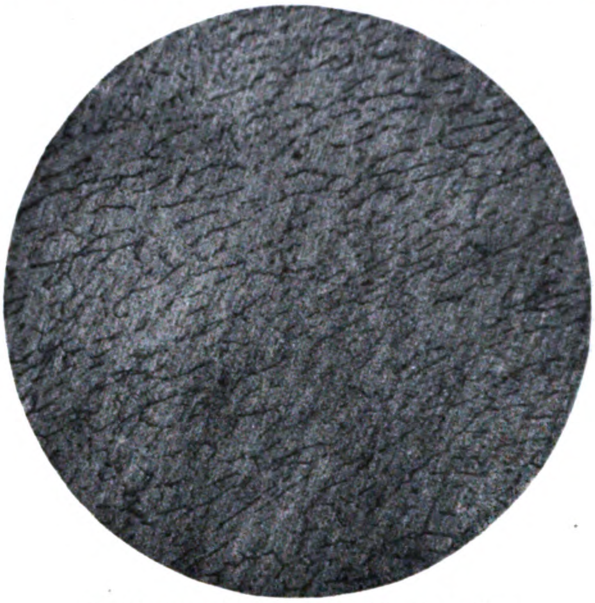


Fig. 10. Sheet Aluminum Containing Impurities
(Magnification 100 times)

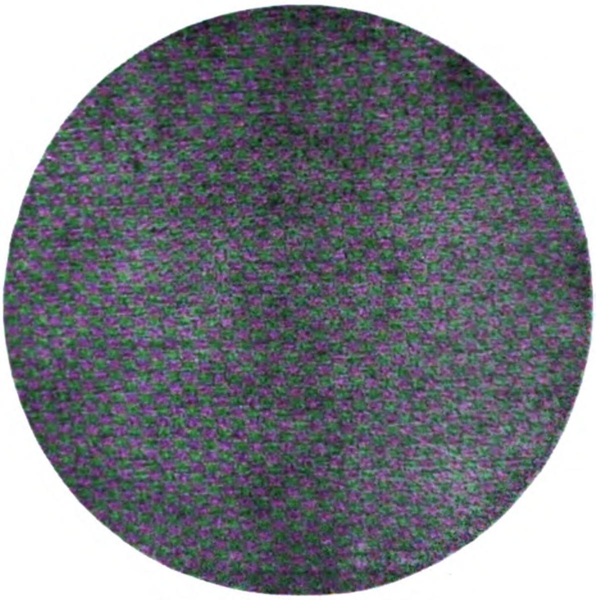


Fig. 11. Aluminum Weld Metal
(Magnification 100 times)

The atomic-hydrogen flame has the property of reducing the majority of metal oxides and therefore gives a clean liquid fusion of most metals. When being welded they have a bright, lustrous appearance.

There are a number of alloys consisting of two or more elements, similar to brass, which melt and evaporate at widely different temperatures. If care is not taken in the welding of these alloys, the deposited metal will appear very porous. Solid welds of brass have been obtained when the filler rod was added to the welded area after the edges had been melted, but the deposited metal should not be remelted after it has been allowed to freeze. Added filler-rod metal should always follow the flame, never lead it, for unless this precaution is taken the zinc will evaporate from the weld at a very high rate. Zinc alone, however, may be welded with the atomic-hydrogen flame without noticeable loss, with resulting welds of about the same ductility as the parent metal in a rolled condition.

The best copper-to-copper welds are obtained with deoxidized copper. Welds of ordinary commercial copper however may be bent through an angle of 180 deg. Good welding results have been obtained with both commercial and deoxidized copper in connection with the cold rolling process where annealing is done between passes. Copper has been successfully applied to the surfaces of many metals, as is illustrated in Figs. 13, 14 and 15.

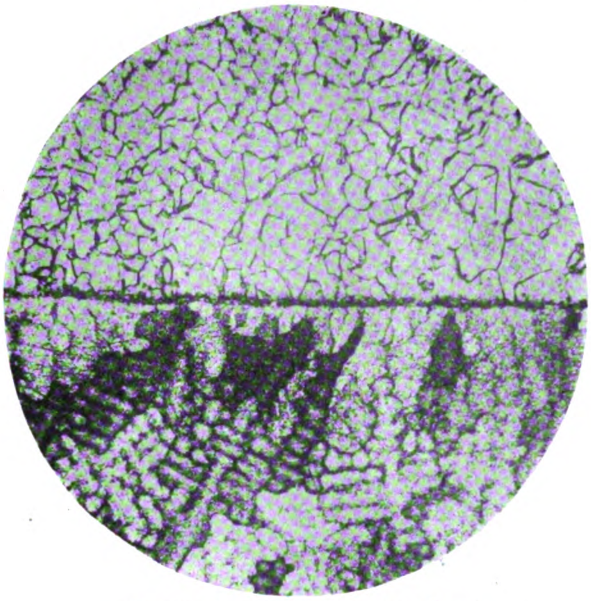


Fig. 12. Sheet Brass to Sheet Steel Weld
(Magnification 100 times)

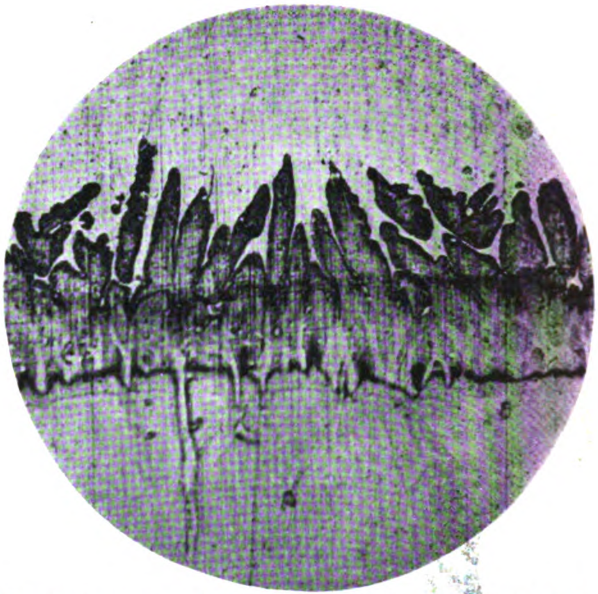


Fig. 14. Copper Deposited on Invar (35 Per Cent Nickel Steel)
(Magnification 500 times)

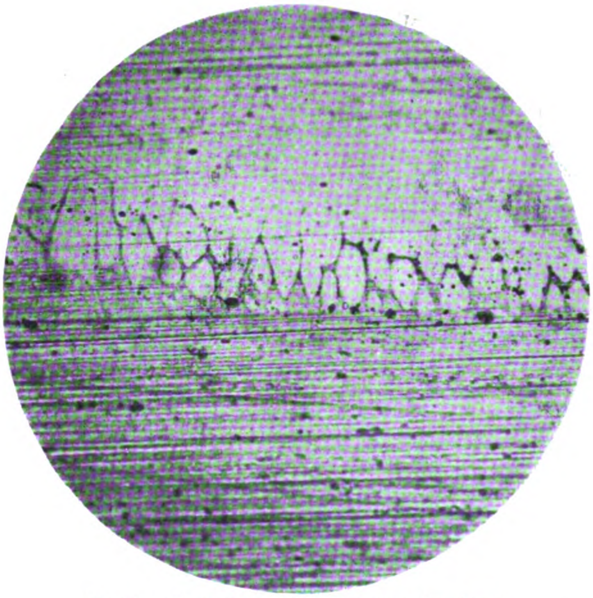


Fig. 13. Copper Deposited on Low-carbon Steel
(Magnification 500 times)

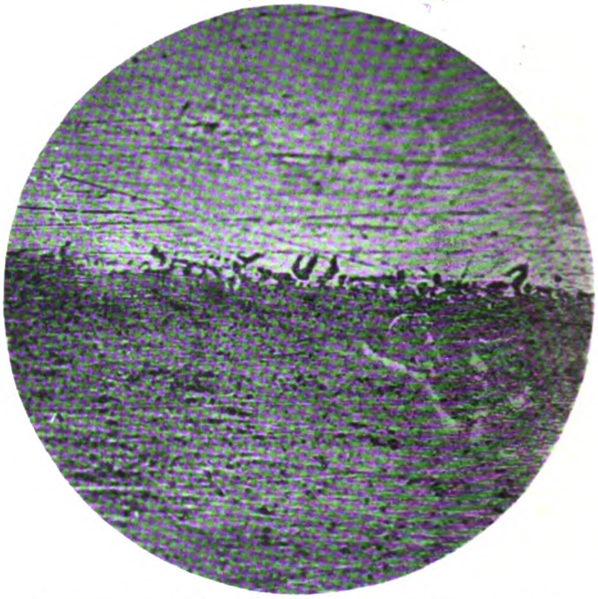


Fig. 15. Copper Deposited on 26 Per Cent Chrominum Steel
(Magnification 500 times)

Monel metal-to-monel metal welds are being made extensively in the manufacturing industries with excellent results.

Nickel when in solid solution free from gases in either the welding rod or rolled metal gives good results. If nickel containing gases is remelted in the atomic-hydrogen flame, these gases may be liberated if sufficient time is given between melting and freezing.

So far, the atomic-hydrogen flame has been used largely to weld metals and alloys that have given difficulty when other forms of welding have been tried. It has also made possible the making of edge and lap welds of different metals when no additional metal is added.

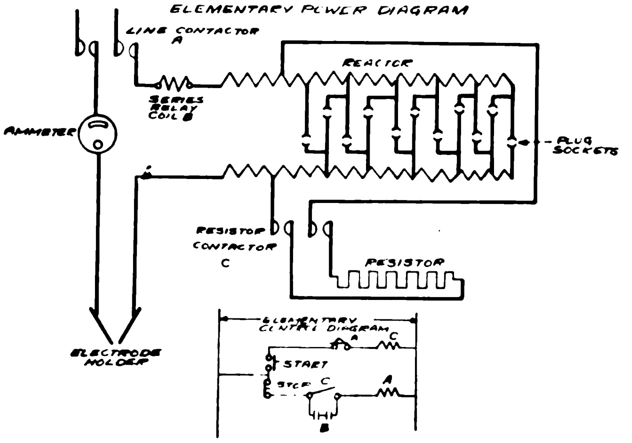


Fig. 16. Elementary Circuit Diagram of the Atomic-hydrogen Welding Equipment

Equipment and Its Operation

The complete atomic-hydrogen welding equipment consists of the following:

(1). One or two insulating transformers for changing the voltage of an a-c. supply circuit to that required for welding.

(2). A control panel mounting a current-controlling reactor, an ammeter, a series relay, a time-limit relay, and auxiliary contactor, a current-selecting plug switch, and a "start and stop" push-button station.

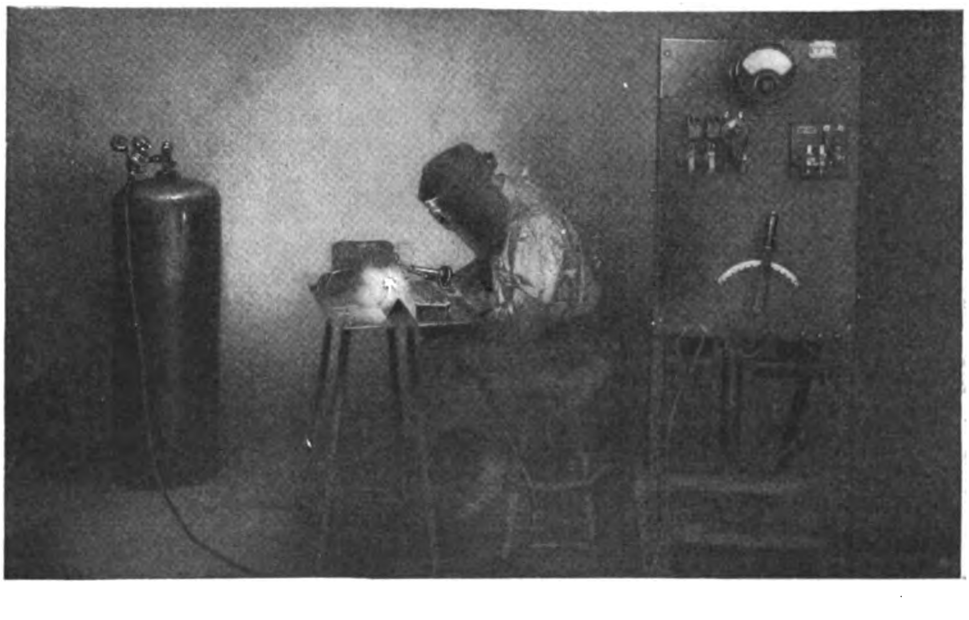
(3). A combined electrode holder and torch.

(4). A supply of tungsten wire electrodes. For welding thin materials using currents not over 35 amp., $\frac{1}{16}$-in. diameter electrodes are employed. For currents over 35 amp., $\frac{1}{8}$-in. or $\frac{3}{16}$-in. diameter electrodes are used.

(5) A welder's helmet.

The reactor is mounted on the back of the control panel, and is composed of a rectangular laminated core having a reactance winding on each of two opposite legs. These coils are connected in series and a number of taps are brought out from each coil. The current passes through the main-line contactor, ammeter, series relay, reactor, and then through the electrode holder and the arc, back to the transformer. It does not enter the "work."

When the operator pushes the "start" button (Fig. 16) the resistor contactor *C* closes and connects the resistor around a portion of the reactor. An interlock on contactor *C* causes the line contactor *A* to close and power is applied to the apparatus. With the resistor so connected and power applied, a high-current condition exists which facilitates striking the arc. Current flowing in the power line causes series relay *B* to close, the contact tips of which form a holding circuit for contactor *A* around the interlock of contactor *C*. A time-delay interlock is normally closed and opens after a definite time, opening contactor *C*. This same result is accomplished earlier in the starting cycle if the arc has been successfully struck by reclosing the "start" button. With connector *C* open, the current value drops to the value determinined by the plug-socket connection. The time-delay interlock is a protective device used to limit the duration of the high-current condition when striking the arc. The apparatus is de-energized by pushing the "stop" button which opens contactor *A*.



Station Air Passages for Vertical-shaft Water-wheel-driven Generators

Development of Ventilation Systems—Descriptions and Examples of Various Types—Practical Advantages and Disadvantages

By EDGAR KNOWLTON
A-c. Engineering Department, General Electric Company

IN the earliest electrical generating stations of all kinds, the machines were placed in a room which was very large as compared with the size and the losses of the machines. For their ventilation the air was taken from and discharged into the room and no very serious consequences resulted.

Later, higher rotative speeds came into use; also higher capacities and higher losses per unit of size. Economies in station construction reduced the relative size of stations, so that the electrical losses per cubic foot of station content were greatly increased. Under these conditions it was no longer satisfactory to ventilate the machines by the earlier methods.

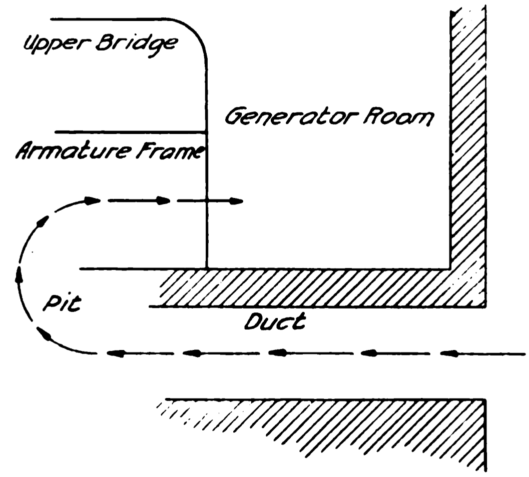


Fig. 1. A Common System of Ventilation for Vertical-shaft Water-wheel-driven Generators

The rapid development of the steam turbine likewise had a great influence on the ventilation of a large class of electrical machinery. The sudden change to speeds several times higher than those formerly used soon showed the necessity of a change in generator and station ventilation. The former practice of taking air from and discharging it into the generator room was discarded. In some cases, the air was taken from outside the building and discharged into the generator room; in other cases the procedure was reversed. Other modifications appeared in due course, so that before the water-wheel speeds increased greatly, the industry had the benefit of the experience with steam turbine generators. One of the most commonly used arrangements for vertical-shaft generators was, and still is, to take the air from outside the station to the pit, thence through the machine, and discharge it into the room.

Still other methods have come into more or less common use; and in the remainder of this article will be described various ways of ventilating vertical-shaft water-wheel driven generators, stating some of the considerations which lead to the choice of a given method.

Air Taken from Outside and Discharged Inside Station

Fig. 1 shows the method of taking air from outside the station through a duct in the foundation and discharging it into the room. It has the advantages of simplicity and of providing a supply of cool air during hot weather. It raises the room temperature an appreciable amount above the outside air, however, and is therefore objectionable during hot weather and advantageous only during cold weather.

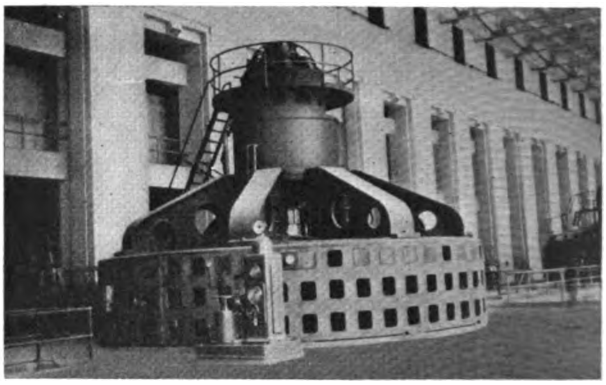


Fig. 2. Station View of Generator Having the Ventilating System Shown in Fig. 1

Fig. 2 shows a view of the interior of a station having this method of ventilation.

Air Taken from Various Localities and Discharged Outside the Station

In the system shown in Fig. 3, a housing surrounding the generator frame collects the air and delivers it outside the building. Air may thus enter either from room or pit, or from both if desirable. In hot weather, the generator room may be kept cooler than with the arrangement shown in Fig. 1.

The machines should be so located that the ducts may be made short, not only with the object of reducing the pressure drop in the duct, but also to keep the generator room as free of obstructions as possible both for the convenience in the operation of the plant, and particularly when erecting and dismantling the machine.

Another modification of this system is that shown in Fig. 4, where the generator is mounted on a foundation at a considerable elevation above the station floor. Here the duct is shown passing from the generator to the station wall under a station gallery.

Doors on the housing allow the discharge of air into the room when desired. In this case, air is taken from the generator room through the various openings in the cylindrical foundation. This arrangement presents a pleasing appearance and is flexible as regards the discharge of air.

Air Discharged Through Station Floor to a Duct (Fig. 5)

When it is undesirable to run a duct across the station floor, the housing may discharge downward into a duct or basement. The air may be taken in from the room or from the pit, or from both places, as mentioned in connection with Fig. 3. A station view of such a system is shown in Fig. 6.

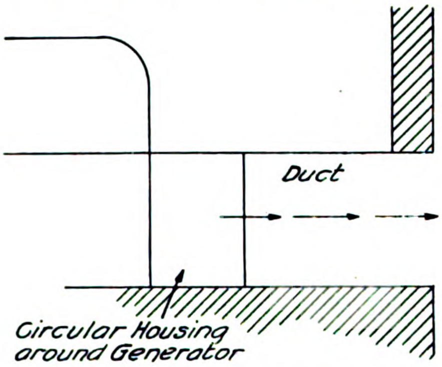


Fig. 3. An Arrangement Whereby Air May be Taken from Either Room or Pit, or from Both, and Discharged Outside the Station

Air Discharged Into a Basement (Fig. 7)

This resembles Fig. 5 in principle, the difference being that the air is discharged into a basement instead of through a duct. Windows in the basement allow the hot air to pass to the outside atmosphere. In this case the operating floor is at the top of the armature frame. Fig. 8 shows a station view of such a machine. This arrangement gives a pleasing appearance to the generator room, but doubtless is more expensive than constructions shown in Figs. 3 or 5.

Machines in Which Air Should be Admitted to Both Ends

In the foregoing descriptions of ventilating arrangements it has been assumed that the proportions and sizes of the generators is such that all of the air could enter at one end of the machine.

In the higher-speed machines this is not true. To obtain sufficient strength in the rotor body the longitudinal openings will be small, or absent, so that the requisite amount of air cannot be taken to the opposite end of the machine from that where it enters. The space between poles is small and is usually obstructed by brackets for retaining the field winding in position. Another difficulty is that, even if these passages were considerably larger, there is no simple way of producing great enough difference of pressure to force sufficient air through these passages. It could be done by a separate blower; but this is not satisfactory, as few companies care to operate an additional piece of apparatus if it can be avoided.

The better solution is to supply air to both ends of the machine. In some cases vertical air passages have been provided in the armature frames to take part of the air from the pit and deliver it to the upper end of the generator. This makes a more expensive frame, since separate passages must be provided for currents of air flowing at right angles to each other, and the frame is larger and more complicated.

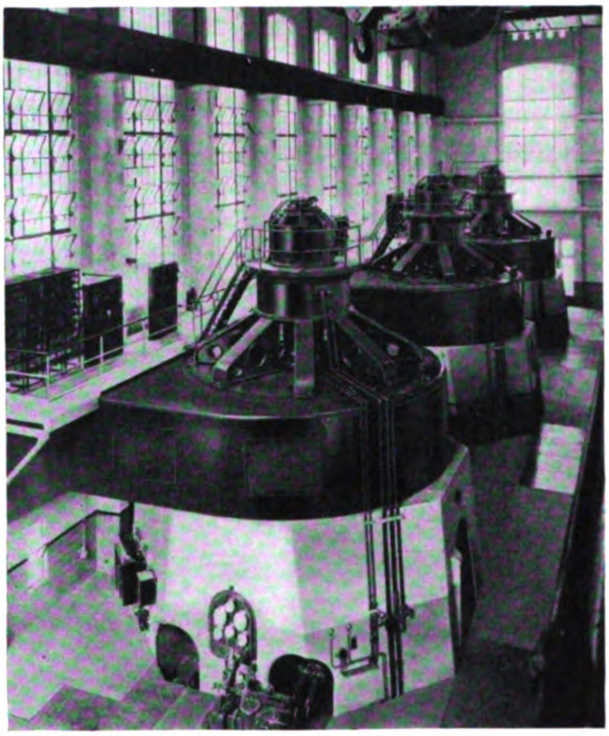


Fig. 4. A Modification of the Ventilating System Shown in Fig. 3

A better way is to provide these passages in a sheet-iron housing encircling the armature frame as shown in Fig. 9. Air enters through the duct from outside the station, part of it going to the top and part to the bottom of the machine.

The outgoing passages may be carried around the housing to a suitable point and connected to a duct leading outside the building.

If it is satisfactory to deliver the air into the room, a housing is unnecessary and the air to the top of the generator may be carried through several vertical ducts alongside the armature frame.

Closed Air System (Fig. 10)

In most water-power stations, the conditions surrounding the site are clean; and dirt does not collect in the machine at an objectionable rate. In a few cases the owners of water-power stations have considered it desirable to have a closed system using surface coolers for removing the heat from the air.

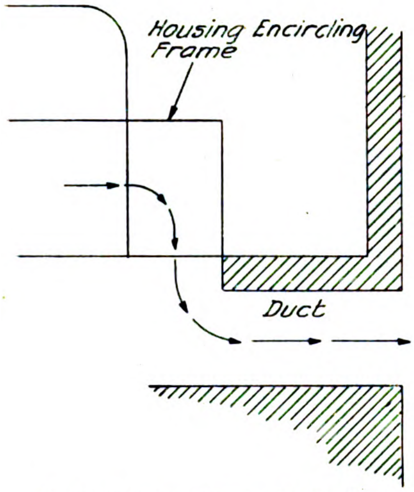


Fig. 5. A System Wherein Air May Enter from Room or Pit, or Both, and be Discharged from Generator Into a Housing which in Turn Discharges Outside the Station Through a Duct Under the Floor

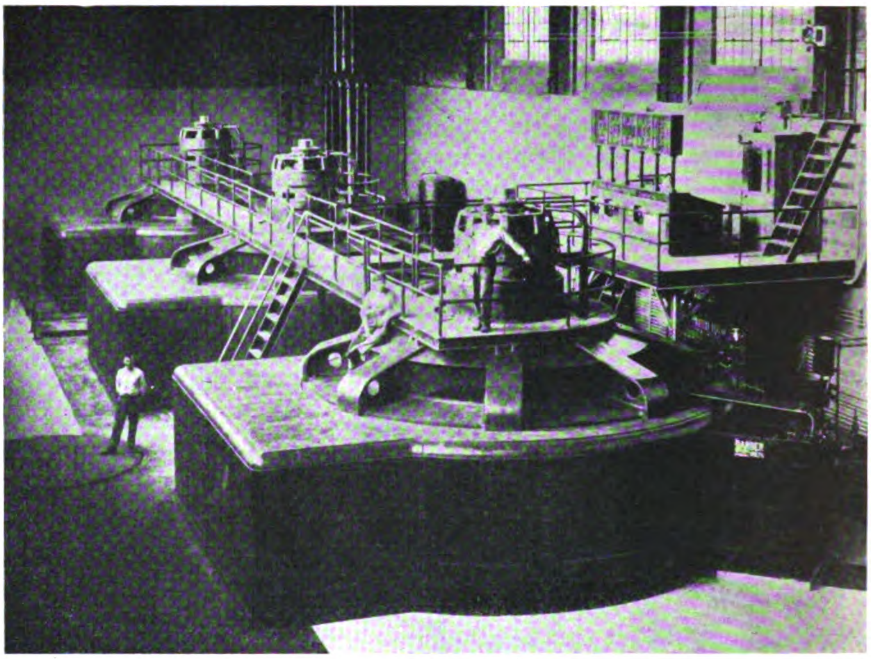


Fig. 6. A Station View of the Ventilating System Shown in Fig. 5

In Fig. 10 is shown the path of the air through the generator and the surface coolers. The coolers are located at intervals in a housing surrounding the armature frame. The arrows represent air paths in a plane parallel to the paper and the circles represent air paths perpendicular to the paper. The vertical-shaft machine is well adapted for surface coolers since the coolers may be located at convenient places around the circumference and any water leakage (which is improbable) cannot enter the vital parts of the machine. Fig. 11 shows a station view of a machine having the closed system.

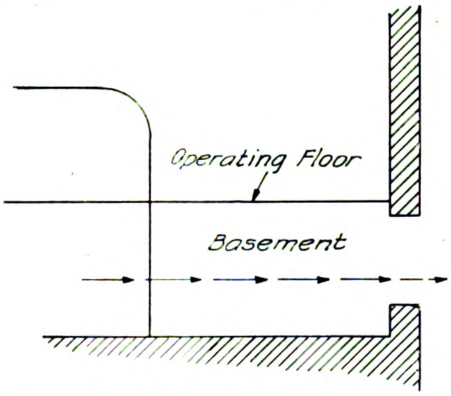


Fig. 7. A System Wherein Air May Enter from Room or Pit, or Both, and be Discharged Into a Basement and from there Outside the Station

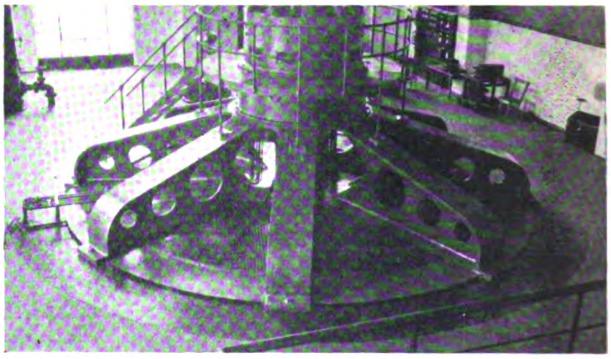


Fig. 8. View of a Generator Arranged as Shown in Fig. 7. Operating Floor at Same Level as Top of Armature Frame

One gallon of water per minute raised 4 deg. C. in temperature will carry away one kilowatt. The temperature rise of water selected depends on several factors, the most important being the temperature of the cooling water. For a temperature of 25 deg. C., about 10 deg. C. may be allowed for the rise of water. For 30 deg. C. water, the rise should be about 5 deg. *i.e.*, the leaving water from the cooler should not exceed 35 deg. C. to have the leaving air temperature 40 deg. C. or less.

Assuming a rise of 7.5 deg. C. in the water, it will require about 350 gal. per minute to cool the air for a 30,000 kv-a. generator, which is the capacity of one shown in Fig. 11.

General

In Figs. 3, 5, and 7 it is obvious that air may be taken from the room, from the pit, or from both places.

One of the considerations of generator and station ventilation should be to provide a comfortable operating room at all seasons of the year. If the ventilating system is inflexible, this object is seldom accomplished. In hot weather the discharging of air from the generator to the room raises the room temperature to an uncomfortable degree; while in cold weather this elevation of temperature is just what is needed.

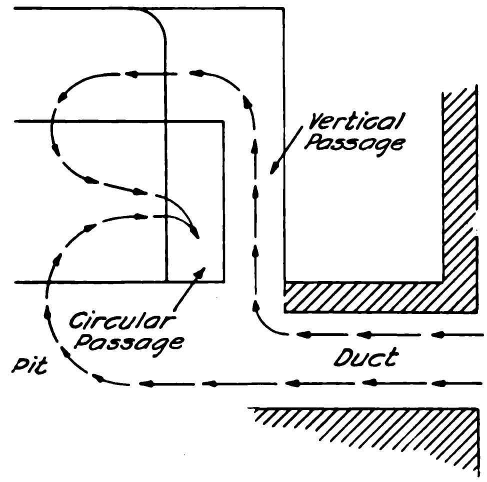


Fig. 9. A System in which Air Enters at Both Ends of the Generator and May be Discharged by Various Paths Not Shown

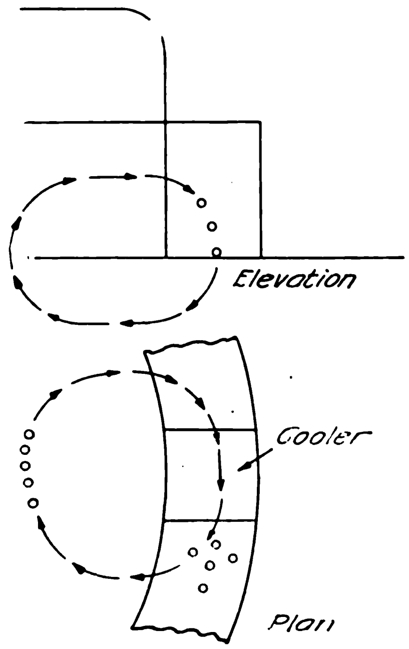


Fig. 10. A Closed System. The Arrows Show Paths Parallel to the Paper and the Circles Shown Paths at Right Angles to the Paper

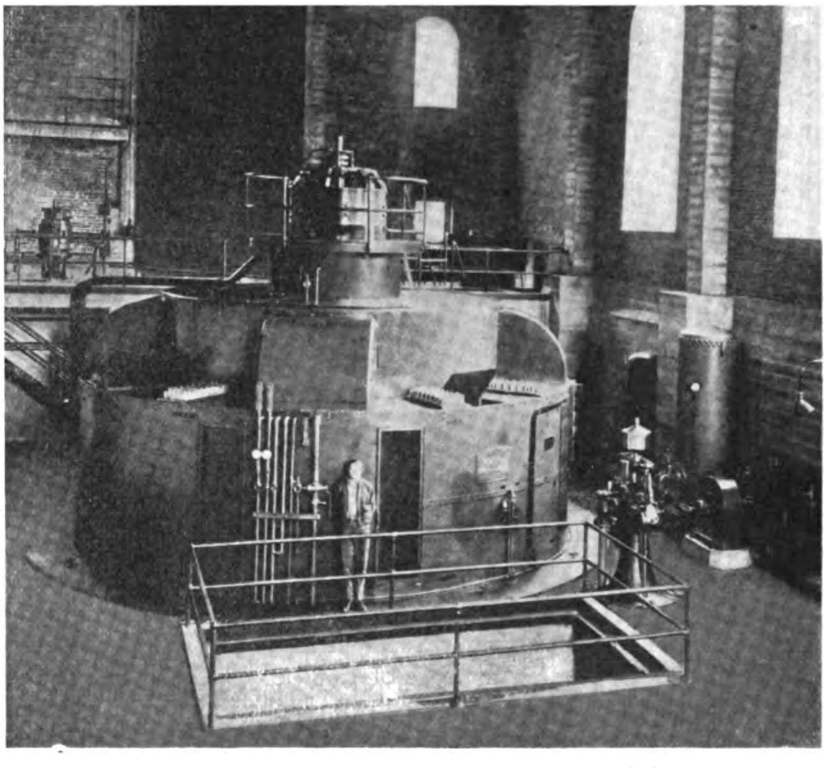


Fig. 11. A Station View of the Closed System of Ventilation

An ideal arrangement is to so design the ventilating system that air may be taken either from the room or out of doors or discharged in both ways also.

Another important reason for this flexibility in the ventilating system is that the life of insulation is considerably increased if the machine is not subjected to extremes of temperature. Sudden changes of temperature are especially serious, and these may be largely avoided by proper installation and manipulation of dampers.

Care should be taken to prevent the outgoing hot air from reëntering the generator. This is necessary even where air is taken from and discharged outside the building; for if the exits and entrances are near each other, the temperature of the cooling air may be too greatly affected by the exit air. Having the entrances and exits on opposite sides of the building is a good arrangement, or a stack may be provided to deliver the hot air at a greater elevation than the air entrance.

It is not good practice to discharge hot air into the water-wheel pit since the operation of bearings, and other parts, may be adversely affected by the higher temperatures.

If very low temperatures are attained in the winter, the taking of air from outside the station into the pit may affect the operation of the governor and other moving parts; and this also has a detrimental influence on the insulation, as previously mentioned.

Electric Operation of the Boston, Revere Beach and Lynn Railroad

Statistics—Description of Railroad System—Cost of Electrification—Electric Train Equipment Power Substations and Distribution System—Signal and Traffic Equipment

By W. D. BEARCE
Transportation Engineering Department, General Electric Company

INTERESTING figures have recently been made public by the Boston, Revere Beach and Lynn Railroad, which began electric operation during November, 1928. The passenger revenue for May, June, and July of this year shows an increase of 10.2 per cent over the same period of the previous year. The actual number of passengers carried increased 10.3 per cent. This improvement is particularly gratifying since other New England electric railways report a decrease in revenues of about 3 per cent for the same period. There was an increase of 1.58 per cent in car-miles operated, so the increased riding must be for the most part attributed to the faster, more regular, and cleaner service provided by the electric trains.

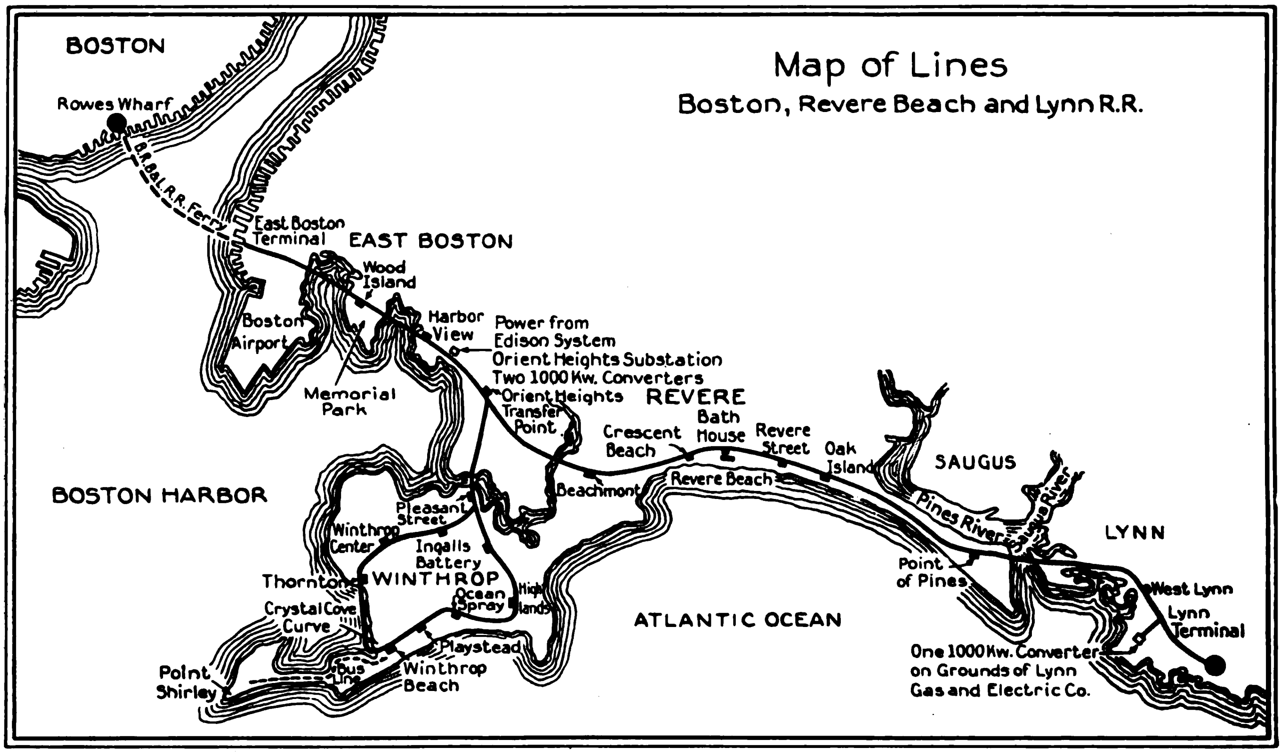

Map of Lines
Boston, Revere Beach and Lynn R.R.
BOSTON
Rowes Wharf
B.R.B.&L.R.R. Ferry
East Boston Terminal
EAST BOSTON
Wood Island
Boston Airport
Harbor View
Power from Edison System
Orient Heights Substation Two 1000 Kw. Converters
Memorial Park
Orient Heights
REVERE
Transfer Point
Crescent Beach
Bath House
Revere Street
Oak Island
SAUGUS
Beachmont
Revere Beach
BOSTON HARBOR
Pleasant Street
Winthrop Center
Ingalls Battery
WINTHROP
Thornton
Ocean Spray
Highlands
Crystal Cove Curve
Point Shirley
Bus Line
Playstead
Winthrop Beach
ATLANTIC OCEAN
Pines River
Saugus River
Point of Pines
LYNN
West Lynn
Lynn Terminal
One 1000 Kw. Converter on Grounds of Lynn Gas and Electric Co.

Fig. 1. Map of Boston, Revere Beach and Lynn Railroad System

The railway operating expenses, despite an increase in miles operated, decreased 18.8 per cent for the first 6 months of 1929. The combination of increased riding with reduced cost of operation has resulted in a decided improvement in net income.

The "Narrow Gauge," as this road is popularly known, has been one of the important rapid-transit passenger lines for the greater city of Boston for more than fifty years. During that period, great changes have taken place in the character of the population and the country through which the road operates. About two years ago the railroad properties came under a new management* known as the Eastern Railway Associates, controlled by Hemphill & Wells and the American Equities Co. Plans were immediately prepared for renovating the entire system.

The steam locomotive power at the time of the change-over consisted of 26 locomotives which had been in operation for many years. The other rolling stock included 96 passenger coaches which were in fairly good physical condition.

The Boston Terminal of this line is at Rowe's Wharf, which is connected with the East Boston Terminal by ferry. The ferry service is handled by four large ferryboats with schedules arranged to meet all trains. The total mileage of this system between the East Boston Terminal and Lynn, and around the branch line to Winthrop, is 13.12 mi. of route with 34.48 mi. of single track.

The communities served include several of the most frequented resorts, such as Revere Beach and

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*The officers of the new company are: Gardner F. Wells, president; Geo. W. Wells, vice-president; and Albert W. Hemphill, treasurer.

Winthrop, and the traffic, therefore, in addition to a large percentage of commuters, comprises an appreciable holiday movement to these resorts. Since electrification, the management has been particularly pleased to note an increase in the number of commuters, as well as the holiday business.

The improved service provided by electric operation includes six and seven-car express-train units operating during rush hour and two or three-car trains operating throughout the day on a 15-minute schedule. During the year 1927, more than 13 million passengers were carried over this system.

In comparison with the former schedule operated by steam, a reduction of 15 min. has been made in the running time between Lynn and Boston. The regular running time between Lynn and Rowe's Wharf in Boston, including the ferry trip, is now 30 min. as compared with previous schedule calling for 45 min. A proportionate reduction in running time has been effected for the citizens of the Winthrop section.

The new equipment was, of necessity, installed without interrupting the existing steam traffic. The erection of the overhead distribution system was largely done at night, when interruptions would occur only once an hour in each direction. It was found that approximately 60 multiple-unit motor cars would be sufficient to handle the service under electric operation. Provision was made for equipping and renovating these cars, a few at a time, making use of cars not required for the schedules. After some of the motor cars had been equipped and the distribution completed, partial service was provided with electric trains for a short time until the remainder of the cars were available for electric operation.

The expenditures for this conversion approximate $1,400,000 as shown in the following table:

Car equipment	$610,000
Substations	152,000
Overhead structures, lines, and feeders	277,000
Signal changes	90,000
Miscellaneous construction including engineering, interest charges, etc.	271,00
	$1,400,000

The direct economies resulting from these improvements, as shown by the operating costs for the first six months of 1929, are in the neighborhood of $160,000 or about 11.5 per cent on the investment.

Rolling Stock

It was decided, after a careful inspection of the existing cars, that they were in satisfactory condition to admit of their being remodeled and electrically equipped. A total of 60 of these cars have been put through the shops and seven additional cars have been remodeled as trailers for use during peak-load periods. The interior of each car has been refinished and operating cabs placed at each end. Thirty 500-watt electric car heating units, consisting of two circuits with 15 units in series, are installed, controlled by a switch mounted at the motor end of the car. Twenty dome-type lighting fixtures are used in each car and these are provided with 32-volt lamps, all connected in series across the trolley circuit. Short-circuiting sockets insure continuous lighting in case of a burned out filament. The headlights used are street-car type portable units which can be attached to the hand rail at the front of each car by means of brackets. These headlights are equipped with 250-watt incandescent lamps with a three-way switch which permits dimming.

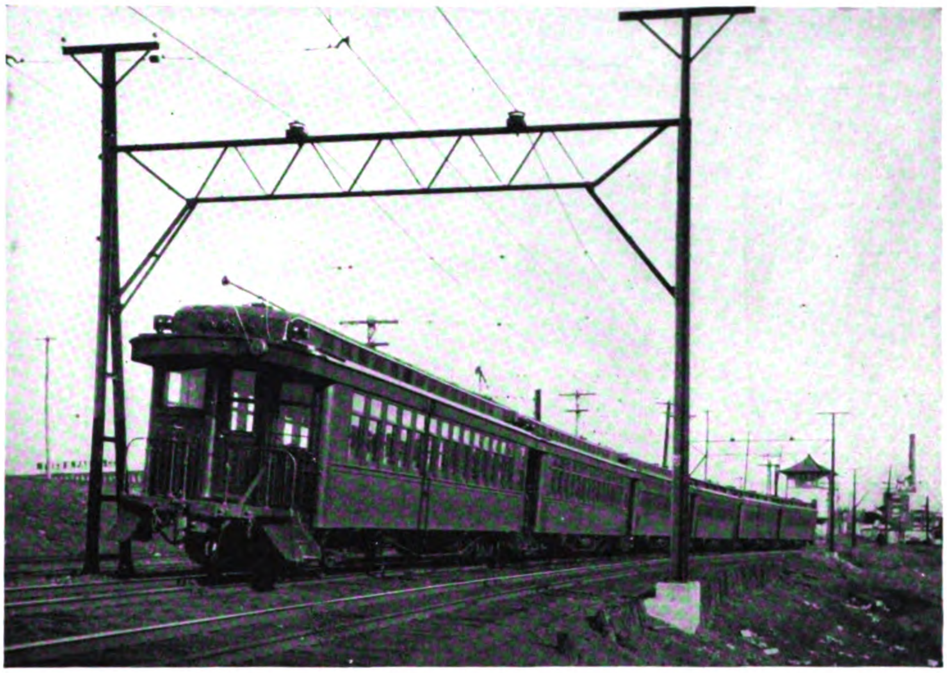


Fig. 2. A Six-car Multiple-unit Train

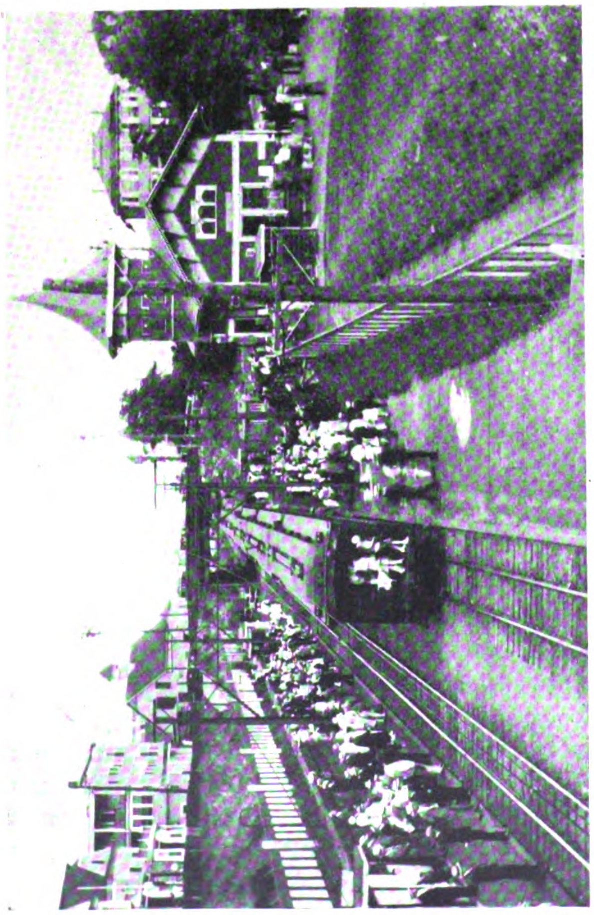


Fig. 3. Electric Trains at Crescent Beach Station. Inbound train in the distance

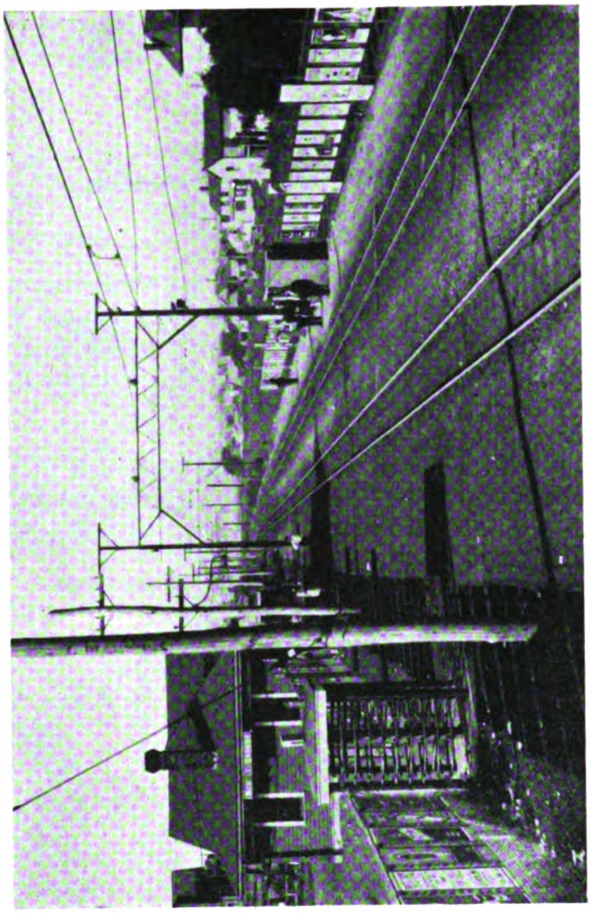


Fig. 4. General Arrangement of Revere Street Station, Showing Overhead Bridges

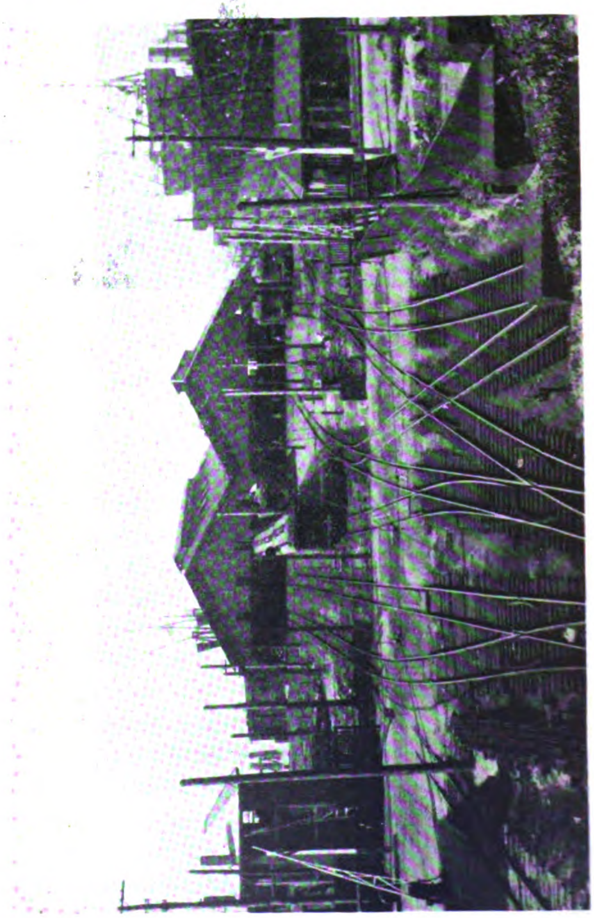


Fig. 5. View of East Boston Terminal, Looking Toward Ferry Slip

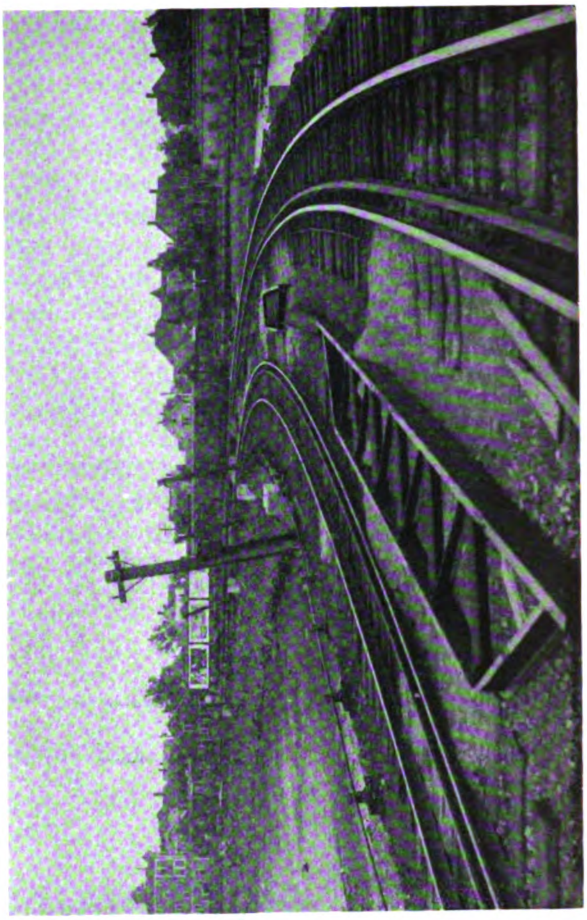


Fig. 6. Crystal Cove Near Winthrop Beach Station, Before Electrification

The motive power includes two GE-295A 600-volt railway motors which are mounted on a new Brill 177-E2 truck. The motors are of the commutating-pole type with provision for tapped-field operation. Each motor weighs, complete with gear, pinion, gear case, etc., 2770 lb. The normal one-hour rating is 60 hp. This motor is of modern design with longitudinal ventilating ducts in the armature, renewable carbon-way brush holders and a multiple ventilating fan which is built integral with the pinion-end armature head.

Control

All cars are equipped with magnetic control, arranged for multiple-unit operation. The main controller is suspended underneath the car body and remotely controlled by a master controller, one of which is located in each operating cab. The electrical connections for multiple-unit control are made overhead by means of coupler sockets located at the ends of each car roof. A 2/0 bus line runs the entire length of each car and is connected to the trolley and the bus-line coupler sockets. All control circuits are supplied from the 600-volt trolley. Current is collected by a 11 ft. 4 in. trolley pole and carried down through the car near a corner post at the motor end.

Air Brakes

The air brakes are of the electro-pneumatic type, using a brake valve with an equalizing piston which provides for pneumatic service application, if for any reason the electric brake is inoperative. There are five positions of the brake valve as follows: release, holding, lap, service, and emergency. In addition to the 60 passenger cars and the seven trailers, four service cars have now been equipped, each carrying two double-motor trucks and using platform-type control. The passenger cars, completely equipped, weigh 52,000 lb.

Substations

Power for the Lynn end of the electrification is furnished by a 1000-kw. 650-volt synchronous converter which is located in the power house of the Lynn Gas and Electric Company. The switching equipment for this unit is of the manual type and the station is operated and maintained by the power company's staff at a fixed charge. The Orient Heights station is located near the junction of the main line with the Winthrop loop. Power is supplied by the Edison Electric Illuminating Company to two 1000-kw. 650-volt synchronous converters equipped for complete automatic control. Two feeders furnish the two trolley wires leading to the East Boston Terminal; a second pair of feeders supply power to the main line going toward Lynn; and a third pair of feeders furnishes power to the Winthrop loop. Reclosing feeders of 2000-amp. capacity are used in the outgoing lines.

Power is supplied to this station by two 3-phase 60-cycle 13,800-volt incoming lines. These are equipped with manually-operated breakers which trip only on reverse current overload. The transformers and alternating-current switching equipment are located outside the station.

An unusual type of ventilation is used for these converters, which consists of a steel housing constructed over each machine in such a way that the converter itself causes a draft of air to flow through

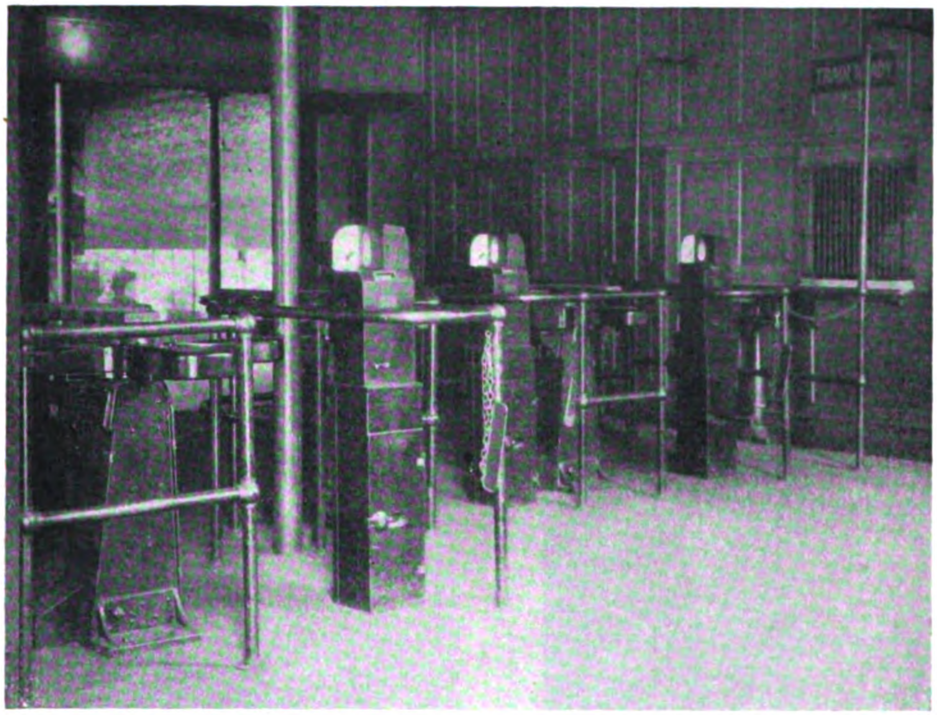


Fig. 7. A Group of Turnstiles at a Prepayment Area

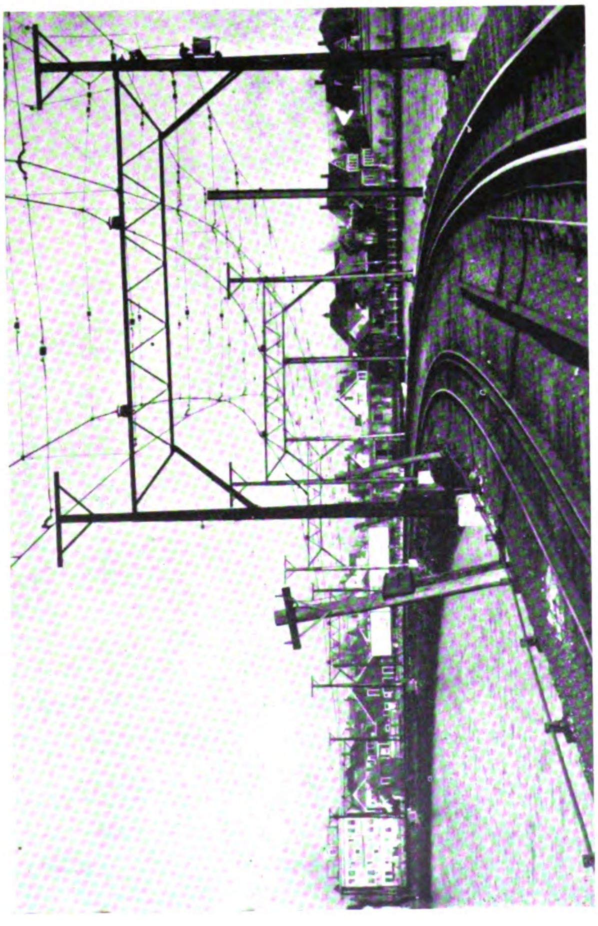


Fig. 8. Crystal Cove Curve, Showing Overhead Construction

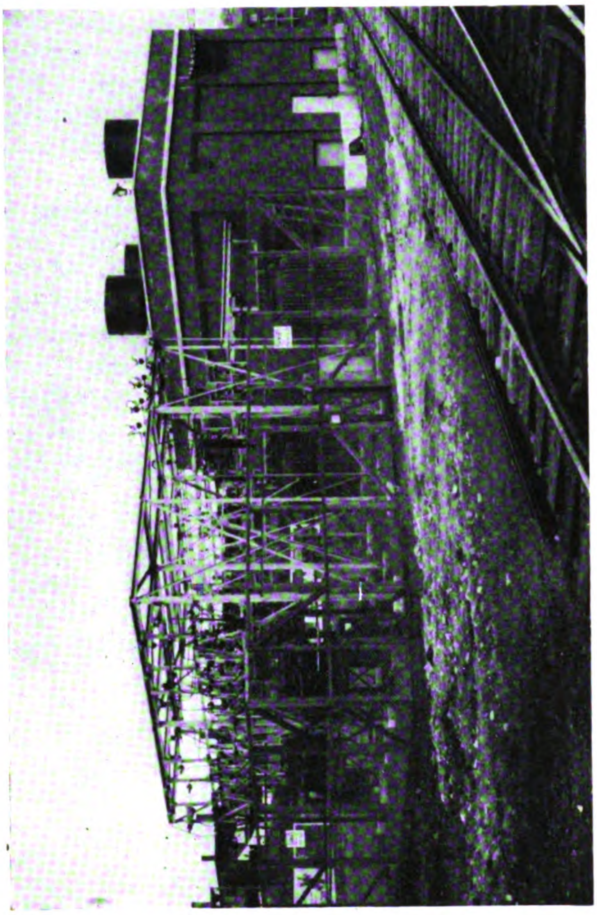


Fig. 9. Orient Heights Substation

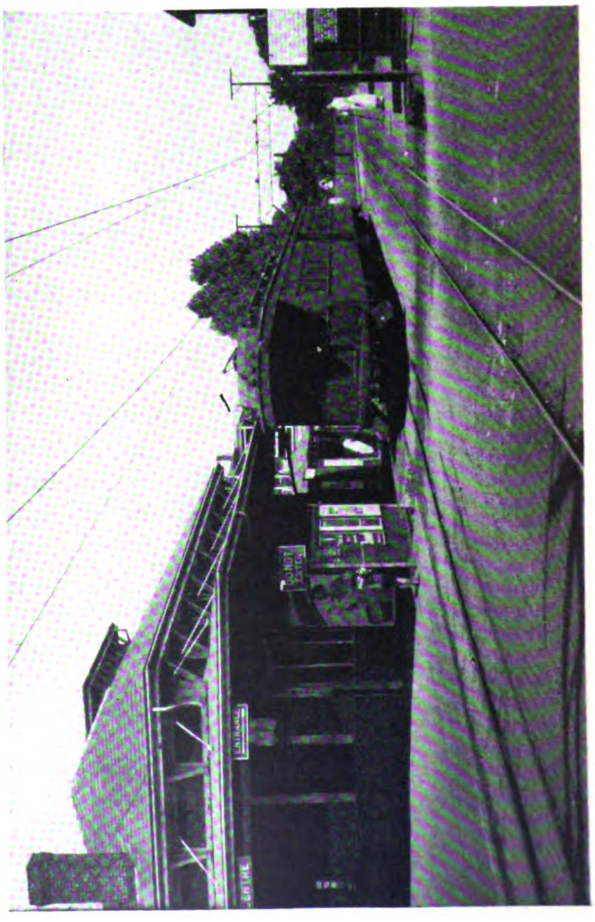


Fig. 10. Winthrop Center Station, and Two-car Electric Train

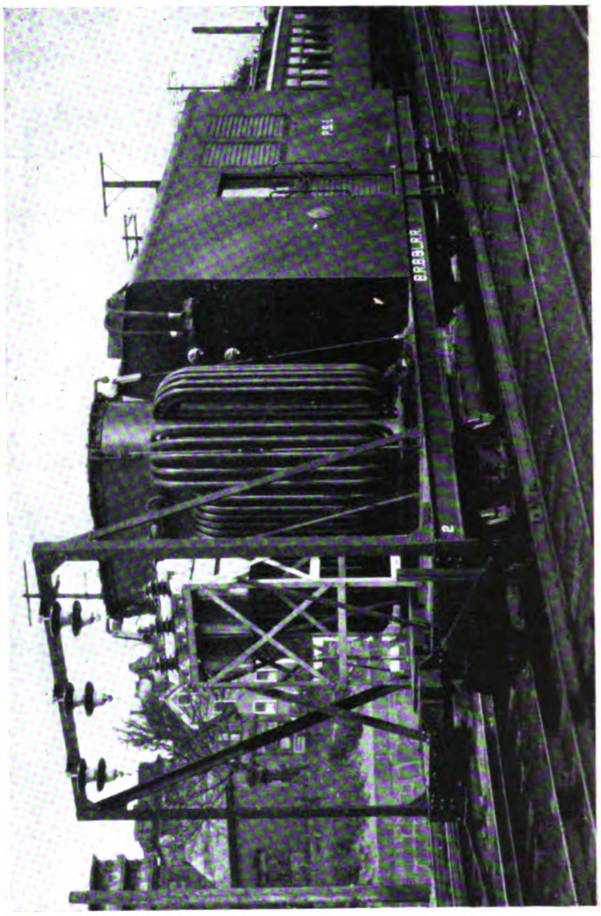


Fig. 11. A 1000-kw. Portable Substation

this housing into a pit underneath the machine and thence through a stack leading through the roof of the station. The warm air from the machine is thus expelled through the roof and the temperature of the machine can be regulated by an adjustable damper located in the outgoing pipe. The housings for this scheme of ventilation are built in sections and can be easily removed without disturbing the converter.

The third substation is a portable unit which also contains a 1000-kw. converter of the same type as those used in the main substations. Provision is made for connecting this station either at the Orient Heights or the Lynn substation where 13,800 volts is available for the portable equipment. The converter is located in a closed section of a steel car, while the transformer and oil circuit breakers are mounted on the other end of the car on the open platform.

Distribution System

The overhead distribution is unusual in a number of respects, but in general represents the latest practice in 600-volt direct-current distribution. The catenary-supporting structures are steel bridges spaced at a maximum distance of 300 ft. apart. Signal and power wires are carried on steel cross-arms located at a height of 5 ft. above the top of the bridge. Unusually large foundations were necessary on account of the character of the soil. These are of concrete being 7 ft. 6 in. deep, 8 ft. long and 2 ft. wide and sunk 6 ft. below the surface. The foundations for the three track towers are 6 ft. by 9 ft. by 2 ft.

On curved sections, the trolley wire is held over the track by steel pull-off poles. These poles are also set in concrete and are braced laterally. Altogether there are 262 bridges and 161 pull-off poles. A feature of this installation is the use of corrosion-proof steel on account of the possibility of damage due to the salt air.

Ample conductivity is provided by a 500,000 circular-mil copper cable which serves both as a messenger and a feeder. This type of construction is used over the entire system. The contact wire supported from this feeder messenger is a 4/0 grooved trolley wire which is 99½ per cent bronze and ½ per cent cadmium. Messenger and trolley wire are bonded at intervals of about 600 ft. All hangers and castings are of non-ferrous material to eliminate possibility of corrosion.

Direct suspension is used in the yards and sidings and, to avoid corrosion in this type of construction, all span wires are of red brass. It was not found necessary to use a negative return as the tracks are all on private right of way and the bonded rails seemed to be ample for handling the return current.

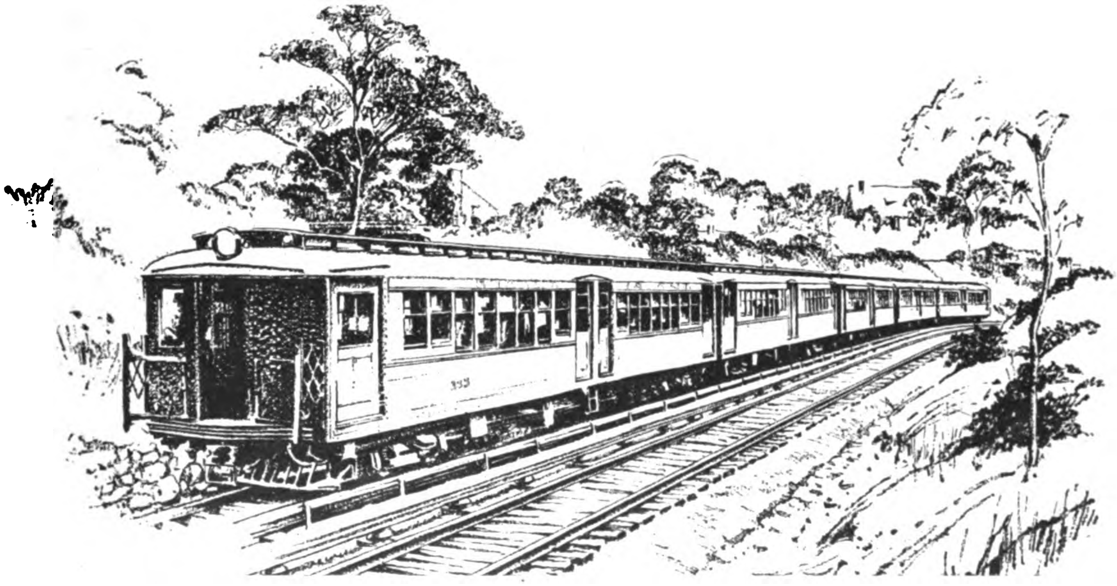
The existing rails were 4½ in. 60 lb. ASCE type and these are bonded with 4/0 7½-in. bonds, acetylene-welded. In some cases it was necessary to lower the grade under the bridges to provide additional clearance. Some changes were also made in the alignment to provide for speeds of from 35 to 45 miles per hour.

Signal Equipment

New signal equipment furnished by the Union Switch and Signal Company included a number of automatic block color light signals which are operated from the 2300-volt line through 60-cycle ¾-kv-a. distribution transformers.

Turnstiles

Some little time prior to the beginning of electric operation the prepayment system of fare collection was instituted at all of the principal stations. This system uses a total of 19 turnstiles with prepayment areas fenced off around the station. Provision is made for handling the maximum traffic with expedition at a minimum expense. At the Rowe's Wharf station, where only 250-volt direct current is available, two 5-hp. motor-generator sets are installed which deliver 600-volt current for operating the turnstiles at this point.



Experimental Solution of Electrostatic Problems

PART II: SOLUTION OF LAPLACE'S EQUATION

By DR. JOHN LABUS
Electrical Laboratory, Union College

IN the first part of this article* it was shown how the potential at any point of an electrostatic field is determined by an experiment. The complete solution, which is based upon Green's theorem, is obtained partly from the experiment, partly by a mechanical integration. In the experiment a charge is placed at the point whose potential is to be determined, and the distribution of the electrical charges along the grounded boundary of the given region is found. The unknown potential is then obtained by integration of these charges, multiplied by the given potential at the boundary, the integral being taken over the boundary. By this method a number of readings have to be taken in order to get the solution for a single point.

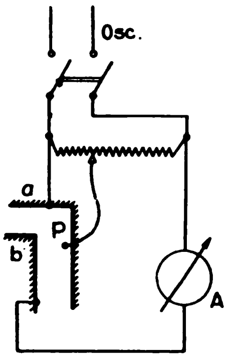


Fig. 19. Schematic Diagram of a Circuit for the Determination of Electrostatic Distribution

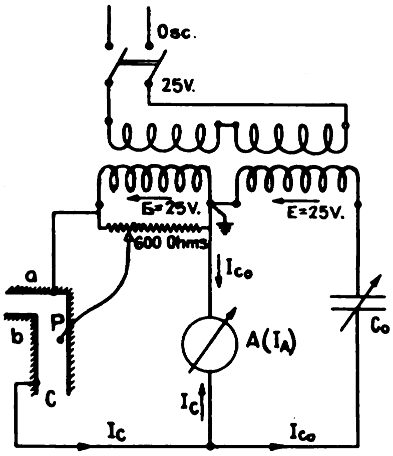


Fig. 20. Requirements of Circuit for Securing Accuracy in Measurements

This method will be applied if, for a given shape of the region, the distribution of the potential inside of it is required for different boundary conditions (the potential distribution at the boundary) or if these are difficult to determine in an experiment as described in this part of the article. In the first case only the integration has to be repeated, since the result of the first experiment depends only on the geometrical configuration of the region and not on the distribution of the potential along the boundary. Another restriction to the universal application of the first method is that it does not lend itself to cases where the dielectric constant has not the same value within the whole region, for instance, as in an oil-type transformer with insulating cylinders between the windings.

Another method will be described, which works faster and which can be applied in cases where the previous method fails. Again, only fields which are uniform in one direction (for instance the vertical one to which we shall refer in the following) or so-called two-dimensional fields will be investigated.

It is known that in this case the distribution of the density of the electrical field does not change theoretically if a thin metallic wire be placed vertically at any point. The wire assumes the potential which existed at the point prior to its insertion there. If the wire be connected, however, to a source of variable voltage, the total charge, which is bound at the boundary of the region, will change. Bearing this in mind, let us consider Fig. 19. The given region bounded by the lines a and b is put across an a-c. source (an oscillator generating about 25 volts of a frequency of 1000 cycles). The total charging current, being proportional to the charge at a or b, is indicated by an adequate ammeter. This ammeter was an Heising tube voltmeter; and since the measured current was of a very low order (about 10^{-8} amperes), it was sent in series with the input transformer of the voltmeter and thus the amplified voltage of the latter was measured. The vertical wire at P is connected to the slide contact of a potentiometer by means of which the potential at P can be changed arbitrarily between zero and E (E is the full voltage across a and b). In so doing, it will be seen that the deflection of the ammeter (A) varies.

If we were to perform an experiment as shown diagrammatically in Fig. 19, we would note that the changes of the charging current obtained by moving the slide contact of the potentiometer back and forth are very small. For an accurate reading, however, it is necessary to have these changes great enough to produce a clearly visible deflection. Fig. 20 shows the way to reduce the total current flowing through the ammeter and to make the variation large.

The oscillator is connected to a transformer whose secondary side consists of two coils, so that the midpoint of the secondary side can be tapped. One half of this winding is put across a model of the region to be investigated and the ammeter, the other sends a current through a balancing condenser of variable capacity, so that the tap becomes the common point of both circuits. On account of the phase of the voltages of the two windings, currents of almost opposite direction will flow through the ammeter. The capacity (C_0) of the balancing condenser can be adjusted until the deflection becomes a minimum, corresponding to the components in phase with the voltage, *i.e.*, the work component caused by the losses in the model (C) and the balancing condenser (C_o).

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*Part I appeared in the July issue of the REVIEW.—ED.

In Fig. 21(a) the corresponding vector relation is represented. Figs. 21(b) and 21(c) show that the resulting current (I_A) increases in both cases, if the current I_c flowing through the model increases or decreases (by varying the potential of the wire at P).

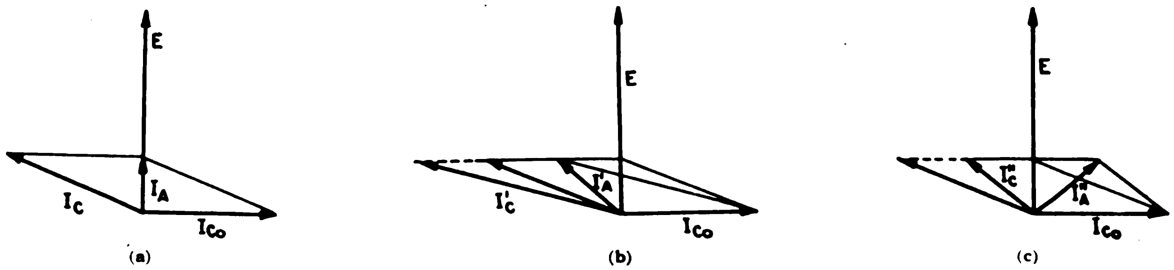

Fig. 21. Vector Relationships Involved in Measurement

This is a further advantage, as it is not necessary to know the value of the total charging current, which incidentally would be subject to changes during the performance of the experiment on account of the voltage drop in the batteries of the oscillator and the tube voltmeter. The voltage drop across the ammeter is very small, compared with the total voltage (E). In one of the given cases it was 0.004 volt ($E = 25$ volts). Therefore the voltage across the model is practically equal to the voltage (E) across the potentiometer.

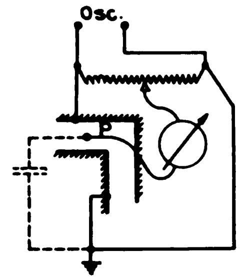

Fig. 22. Diagram of a Circuit Unsuitable for Measurement of Charging Current

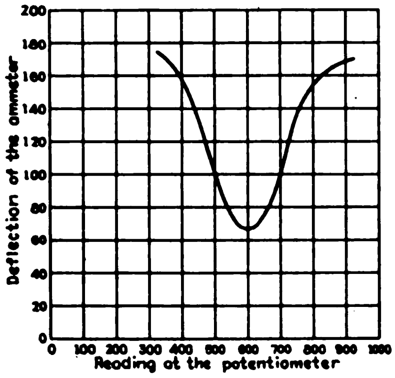

Fig. 23. Plot of Ammeter Deflections Against Different Voltages of the Exploring Wire, the Unknown Potential at P (of the Undisturbed Field) Being $\frac{600}{1000}$ E for This Point

The question may arise: Why do we not measure directly the changes of the charging current or the current which flows to the wire as it is shown in Fig. 22? This method was tried first of all; but it proved a failure, because the charging current flowing through the capacity of the wire to ground (dotted line) flows in this case through the ammeter, and its value changes as the potential of the wire is varied.

Returning to the experiment, attention will be called to Fig. 23 in which the deflections of the ammeter have been plotted (in one position of the exploring wire) against different voltages at the wire, read on the potentiometer. The curve shows a minimum at $600 \frac{E}{1000}$, which was the unknown potential at P.

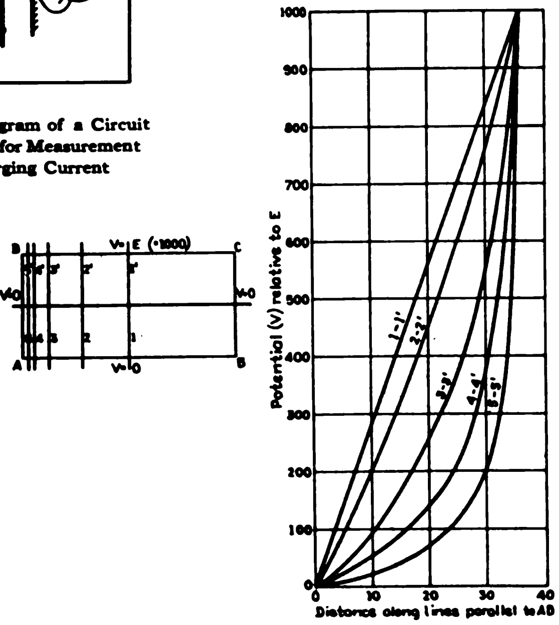

Fig. 24. Distribution of Potential Inside a Rectangle, Where $V = E$ at One Side (CD) and $V = 0$ at the Others

The best way to get this minimum is to so adjust the potentiometer that the pointer of the ammeter coincides with a scale line. Then the slide contact is moved until the pointer passes through a minimum deflection and then reaches again its previous position. The required potential is the average value of two readings at the potentiometer. In Fig. 23 we would have, for instance: $e = \frac{630 + 570}{2} = 600$ (the potentiometer scale has 1000 degrees). This method proves an advantage in cases where the curve (Fig. 23) is very flat around the minimum. Then it might be difficult to get the reading. This is especially true when the wire is far away from the part of the boundary which is connected to the ammeter. This difficulty however, can be overcome by interchanging the connections leading to a and b (Fig. 20). The reading secured in the way described gives the right value since the curve in Fig. 23 is practically symmetrical with respect to the minimum.

After all the connections are made, the balancing condenser is adjusted. For this purpose, the potential of at least one point of the region to be investigated must be known. We know at least the potential at a ($V=E$) and at b ($V=0$). The exploring wire is put at such a place and the slide of the potentiometer is moved to the corresponding potential. Then the balancing condenser is adjusted until the deflection of the ammeter becomes a minimum (I_A). It is better to do it in this way by leaving the wire inside the model, instead of removing it; otherwise it might cause some inaccuracy. In the experiments performed, the balancing condenser consisted of two metal plates about 10 cm. in diameter, the distance between the plates being different for the different models. It is of great importance to make the adjustment of this condenser as carefully as possible, since this influences greatly the results. Greater accuracy can be obtained if a micrometeric adjustment is used.

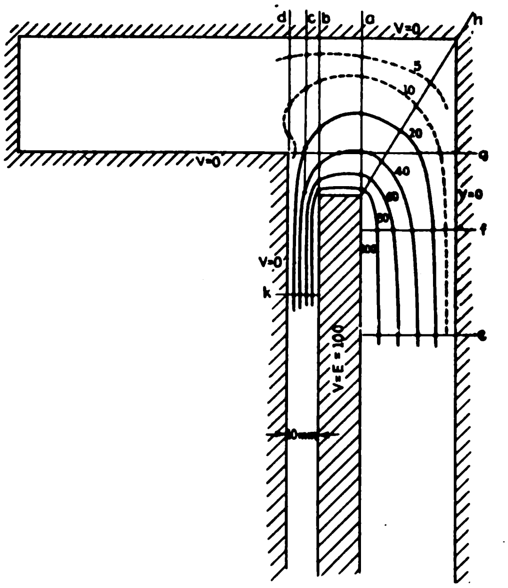

Fig. 25. Equipotential Lines of the Electrostatic Field of a Transformer. The voltage along the winding is assumed to be the same for all points

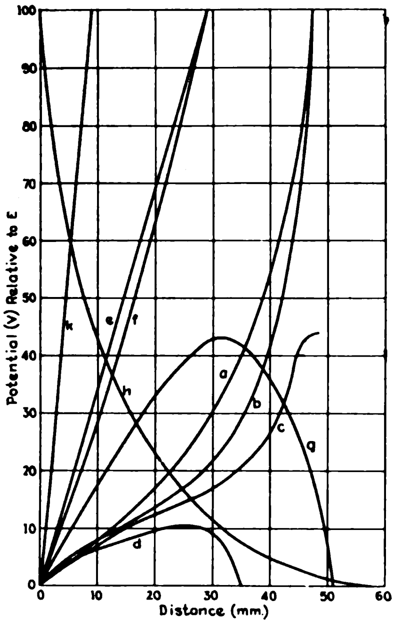

Fig. 26. Potential Along Lines *a, b, c, d, e, f, g, h,* and *k* in Fig. 25

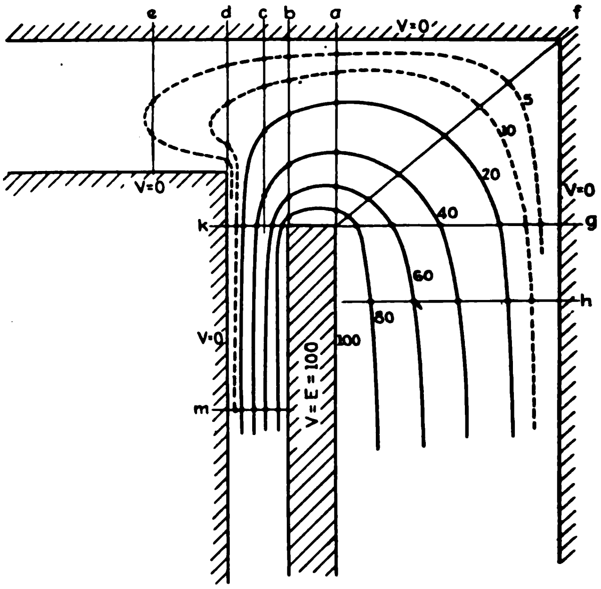

Fig. 27. Equipotential Lines of the Electrostatic Field of Another Transformer Than That of Fig. 25. The voltage is again assumed the same for all points

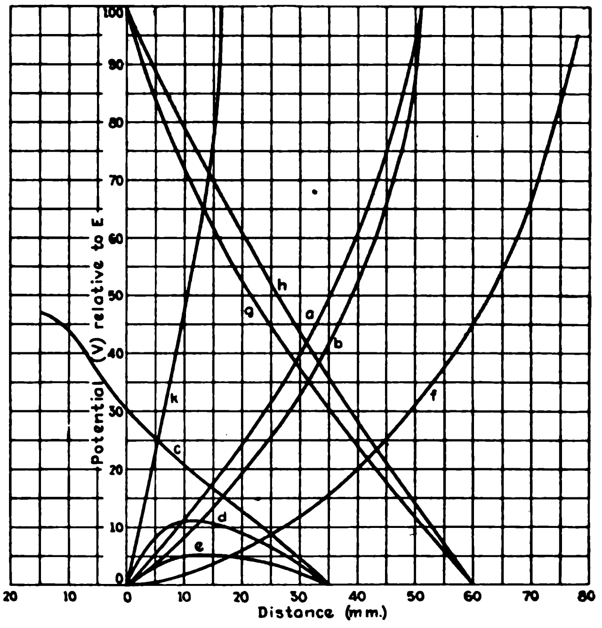

Fig. 28. Potential Along Lines *a, b, c, d, e, f, g, h,* and *k* in Fig. 27

The model is built up of boards, forming the boundary of the region to be investigated, on the inside of which tin foil is glued. In order to have the electric field uniform in the vertical direction, the tin foil is divided in three parts, separated by small gaps. Only the middle section of *b* (Fig. 20) is connected to the ammeter, whereas the other two are grounded, thus acting as guard rings. The result depends on the uniformity of the field within the measured section and therefore it is necessary to make the guard rings very high. Their height was 8.5 cm.; the middle section was 5 cm. high. It was found, however, that for the area of the given regions, the guard rings could be still higher. All the leads, and the model itself, must be carefully shielded and everything must be avoided which would disturb the field inside of the model. In the given cases now to be considered, the outsides of walls of the model were also covered with tin foil and grounded. Furthermore, the balancing condenser was placed in a shielding cage.

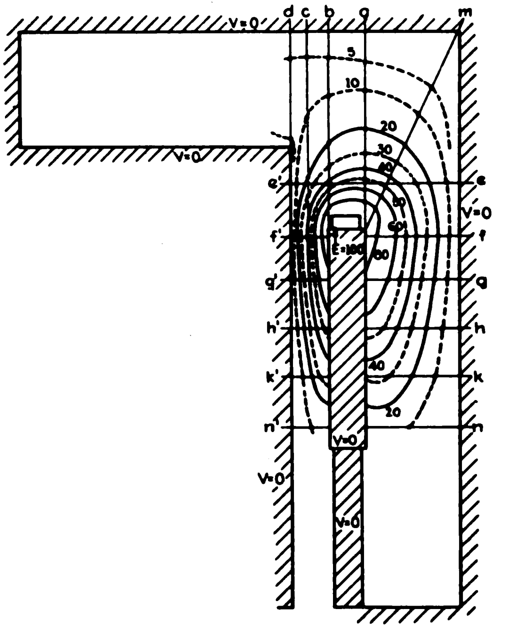

Fig. 29. Equipotential Distribution in a Transformer. The fact that the voltage drops linearly along the section of the winding is taken into account

In order to check the results of this method, the investigation of a rectangle has been taken up. The curves in Fig. 24 so correspond to Fig. 17, in the first part of this article.

In the same way the potential distribution of the electric field of two transformers (Fig. 25 and 27) has been investigated. Contrary to reality, the potential at the surface of the winding has been made the same for all points of it. Fig. 29 then shows a case in which the linear voltage drop along the winding has been considered. It has been reproduced by winding around the piece which represents the winding of the transformer a wire of high resistance. Thus the voltage drops linearly along this part of the boundary. In the other instances (Figs. 26, 28, 30, and 31) the potential is plotted along certain lines within the regions as it was formed by the experiment. The lines of equal potential (Figs. 25, 27 and 29) have been drawn by means of these curves. It may be mentioned that the latter case is very difficult to deal with mathematically(2) and results can be found in that way only by making certain restricting assumptions. Apart from the condition that the field must be uniform in a third dimension, no other assumption was necessary in the experimental method.

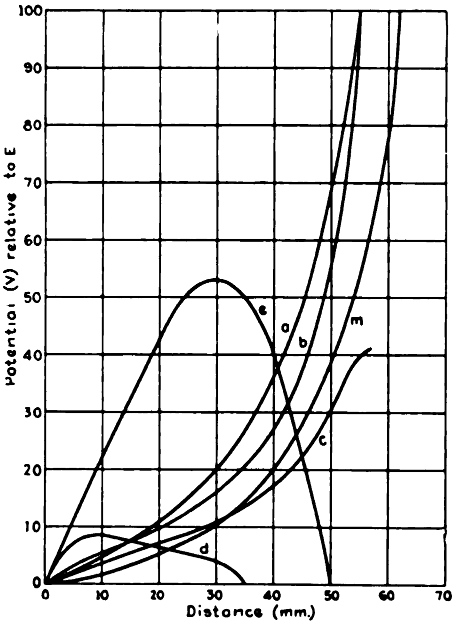

Fig. 30. Potential Along Lines *a*, *b*, *c*, *d*, *e*, and *m* in Fig. 29

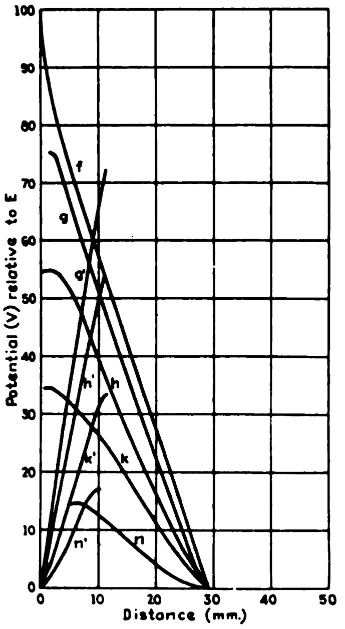

Fig. 31. Potential Along Lines *f*, *g*, *h*, *k*, *n*, and *g'*, *h'*, *k'*, *n'* in Fig. 29

The writer is greatly indebted to Union College, and in particular to Dr. Ernst J. Berg, of the Electrical Engineering Department, for his interest and for the opportunity to carry on these investigations.

(*Concluded*)

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(2) *Archiv für Elektrotechnik*, Bd. XXI, 1928, p. 250.

A Study of Crystal Structure and Its Applications

PART XIII

CRYSTAL STRUCTURE AND VALENCE

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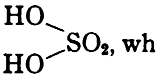
THROUGHOUT the development of the science of chemistry, there have been few single topics which have received the thought and research which has been applied to the matter of chemical valence. The whole thing seemed quite simple at first. The regularity and simplicity of the ratios by which the elements combined to form the compounds whose composition was then known made the valence problem a simple one indeed. The early discovery that some elements had more than one combining weight, however, made necessary an immediate amplification of the theory. From that time to this, the struggle to keep the theory apace with the known facts has been continuous. From a *practical* standpoint, the theory has always kept a jump ahead of the facts in some fields. At the same time that it failed to account for the existence of carnallite, $KCl \cdot MgCl_2 \cdot 6H_2O$, it could predict compounds of almost unbelievable complexity, both organic and inorganic. Perhaps the great interest in this theory is to be accounted for in some measure by the fact that it has been so fruitful, at the same time the exceptions have been so baffling.

For a number of reasons, it is to be expected that x-ray diffraction methods should offer very valuable data pertaining to the existing theories of valence. In the first place, there are many compounds in which chemical evidence gives no clue to the arrangement of the atoms within the molecule. The case of carnallite just mentioned is an example. Furthermore, many of the compounds which have caused the most difficulty in connection with this theory are known only in the solid state. The salt just mentioned and the alums offer examples of this type. In addition, there has always been some question as to the equivalence of atoms in certain groups. There is still a tendency to write the structural formula of sulphuric acid in the way that accounts for those reactions which point to the presence of hydroxyl groups,  $\genfrac{}{}{0pt}{}{HO}{HO}\!\!>SO_2$, while theoretical considerations seem to favor the view that the four oxygen atoms are equivalent and the hydrogen atoms are attached to the group as a whole, as illustrated by the Wernerian formula, $[SO_4]H_2$. In all of these cases, the x-ray is the only tool which can give us direct information concerning the special relations of the various atoms which make up the solid substance.

Various Types of Chemical Combination

Before considering the data which have resulted from crystal structure researches thus far, it will be of interest to review in detail a few of the various types of compounds in relation to the modern viewpoint of valence in order to see just what information is lacking that the x-ray might be hoped to give. First of all, we have a host of compounds which are known in the liquid and gaseous states, as well as the solid, whose molecular configurations are well known. In ethylene bromide $CH_2Br \cdot CH_2Br$, we know with certainty that the two carbons are linked together and that each has two hydrogen atoms and one bromide atom linked to it. We know further that this linkage must be preserved in the solid state; otherwise its isomer, ethylidene bromide, $CH_3 \cdot CHBr_2$, might result when the crystals are again melted. In direct contrast to this class are the binary electrolytes such as sodium chloride. The liquid state of this compound is not so well known, but in the gaseous phase it seems to be well established that molecules of NaCl exist.(163) In the laboratory, crystals of NaCl are usually prepared from aqueous solution. In this dissolved state, it exists largely, if not entirely, as ions. For this reason it is impossible by ordinary physical-chemical methods to place any limitations upon the possible spacial relations of the atoms in the crystal, because they can leave the crystal either as ions or as molecules, depending upon the conditions of the experiment. If they do leave as molecules, it is not necessary that they be paired with the same atoms that they were with before the crystal was formed. We might be led to expect that there would be some difference between

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(163) Nernst and Wartenberg, *Z. Anorg. Chem.*, *56*, 230-36.

References made to material hitherto published in this series of articles may be readily located from the following table:

Part	*Issue*	*Figs.*	*Equations*	*Tables*	*Footnotes*
Part I	Nov., 1924 p. 742	1 and 2	1 to 16	I and II	1 to 13
Part II	Dec., 1924 p. 795	3 to 10	17 to 32	III	22 to 27
Part III	Feb., 1925 p. 129	11 to 22	33 to 37	IV	28 to 42
Part IV	Apr., 1925 p. 258	23 ro 28	38 to 41	None	43 to 48
Part V	May, 1925 p. 342	29 to 35	None	None	49
Part IV	Aug., 1925 p. 286	36 to 51	42	V to VII	50 to 58
Part VII	Oct., 1925 p. 721	52 to 59d	43 to 47	VIII and IX	59 to 65
Part VIII	Feb., 1926 p. 118	60 to 67	48	X to XIII	66 to 82
Part IX	Apr., 1926 p. 274	68 and 69	49 to 56	XIV to XXVI	83 to 117
Part X	Aug., 1926 p. 580	70 and 71	57 to 66	XXVII to XXXI	118 to 131
Part XI	Sept., 1928p. 496	72 to 77	67 to 84	XXXII to XXXIII	132 to 139
Part XII	Nov., 1928p. 612	78 to 92	85 to 98	XXXIV and XXXV	140 to 162

the arrangements adopted in the face of such low requirements and that of the strict requirements of the previous class.

Midway between these two classes lie certain complex ionogens, such as potassium chloroplatinate, K_2PtCl_6. This substance ionizes according to the equation $K_2PtCl_6 \rightleftharpoons 2K^+ + PtCl_6^{--}$. The $PtCl_6^{--}$ ion is quite stable, since the concentrations of Pt^{++++} ions is vanishingly small. The same reasoning which applied to the NaCl, then, will apply to the K^+ ions and the $PtCl_6^{--}$ ions in this case. The chloroplatinate group, however, must appear as a group in the crystal in such manner that throughout its whole history each Pt atom is combined to the same Cl atoms. This latter requirement becomes evident when the compound is considered as a member of the following series,(164) all of which are known:

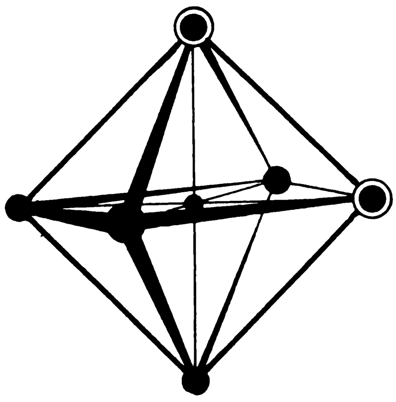

Fig. 93. Cis-$Pt(NH_3)_2Cl_4$ According to the Coördination Theory. The large black dots represent Cl; the small dot in the center represents Pt; the black-centered circles represent NH_3. In the transform, the NH_3 groups would be diametrically opposite one another

1....$[Pt(NH_3)_6]\ Cl_4$	Hexammine-platé chloride
2....$[Pt(NH_3)_5\ Cl]\ Cl_3$	Chloro-pentammine-platé chloride
3....$[Pt(NH_3)_4\ Cl_2]\ Cl_2$	Dichloro-tetrammine-platé chloride
4....$[Pt(NH_3)_3\ Cl_3]\ Cl$	Trichloro-triammine-platé chloride
5....$Pt(NH_3)_2\ Cl_4$	Tetrachloro-diammine-platinum
6....$[Pt(NH_3)\ Cl_5]\ K$	Potassium pentachloro-ammine-platéate
7....$[PtCl_6]\ K_2$	Potassium hexachloro-platéate.

All of these compounds ionize in such a way that the group within the brackets appears as one ion and the atoms outside as the other. The fifth member of the series does not ionize. It is evident that the second, third, and fourth of this series must crystallize in such a way that the complex radical remains intact; otherwise a mixture of two or more of the series would result when the substance was redissolved. Similarly the complex ion of the sixth of the series must remain intact; otherwise it would yield the fifth and seventh on solution. That the end members of the series would be expected to meet the same requirements is a natural extrapolation.

The fifth member of the series is especially interesting as an example of the type of ethylene bromide. According to Werner, the six groups lie around the central platinum on the surface of a spherical shell, marking the points of an octahedron, as shown in Fig. 93. If this is the state of affairs, it is seen at once that two configurations are possible, and we have a case of cis-trans isomerism.(165) As a matter of fact, two forms of this substance are known, but it is not certain which is which. The point of interest here is that in order to preserve these arrangements, the molecule must preserve its identity in the solid. One would expect the octahedron to be somewhat distorted by the presence of two unlike groups, and a determination of the structure of these isomers might serve to identify them.

More or less distinct from the classes of compounds mentioned is the great array of inorganic double salts, minerals, etc., which are known in the solid state only. The alums, for instance, appear to decompose entirely into ions and water molecules when dissolved. It is this class of substances which has offered the greatest difficulty in connection with the Wernerian conception of valence. In fact, it seems that the only hope of an adequate explanation of these compounds lies in the ultimate solution of their crystal structures by x-ray analysis. As will be seen later, there are thus far very little data which shed much light upon the forces within these crystals, but a careful consideration of the problem at this time may be of interest.

Werner's coördination theory had to do originally with certain complex ions and molecules which were known to exist from the reactions of the substance in solution and which were known, therefore, to exist in a state of *ionic* and *molecular* subdivision. In the list of platinum compounds that has been given, it will be noticed that in each case the Pt atom is surrounded with six atoms or molecules, the total number of chlorine atoms and ammonia molecules being the only constant feature of the series of complex ions thus formed. The charge on the ion is seen to be the algebraic sum of the primary valencies of the platinum and chlorine atoms in the groups. From the way in which the compounds ionize, it is evident that those atoms and molecules which are attached to the platinum in coördination positions are much more firmly bound than those atoms which are outside the complex ions.(166) Those groups in coördination positions which are electrically neutral (NH_3, etc.), and the acid groups or atoms in excess of the primary valence of the central atom are supposed to be held to the central atom by secondary valence bonds, while the acid groups within the primary valence of the central atom (together with the groups outside which are necessary to secure electrical neutrality of the molecule as a whole) are held by ordinary primary valence forces—as sodium is bound to chlorine in NaCl. However, the acid groups in coördination positions are held also by secondary valence forces, so that they are forced to play dual roles. It is assumed that in case the negative groups are in excess of the primary valence of the metal, the primary valence forces are distributed uniformly over the entire number, leaving the group negative as a whole. Thus in $Pt(NH_3)Cl_5K$ it is supposed that the chlorine atoms are all equivalent. In the case of $PtCl_6K_2$ it is supposed not only that the chlorine atoms are all equivalent, but also that they have a symmetrical arrangement in space.

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(164) Schwartz and Bass, "The Chemistry of the Inorganic Complex Compounds," p. 35, John Wiley and Sons, 1923.

(165) Schwartz and Bass, op. cit., p. 62.

(166) That is, from the standpoint of ease of ionization, not heat of formation or decomposition.

The extension of this theory to other compounds, such as those containing water of crystallization, was easy and natural. In fact, the conclusion that water molecules enter coördination positions is, in some instances, inescapable. Analogous to the series of platinum salts which has been discussed is the series of cobalt salts(167) of which hexammine-cobalti chloride, $Co(NH_3)_6Cl_3$, is the first member. If one of the ammonia molecules of this compound is removed one of the chlorine atoms takes a coördination position and only two chlorines are ionized in solution. Under certain circumstances, a water molecule can take the place of this chlorine, however, and the chlorine is again ionized. As many as three ammonia molecules in this compound can be replaced by water with all of the chlorines remaining in an ionizable state. If the water molecules are removed by heating, then the chlorine atoms take their places and no longer ionize. So it is seen, in this case at least, that water of crystallization can be explained by Werner's theory of secondary valence. There is also a large number of compounds which have six molecules of water of crystallization which may be assumed to be in coördination positions, although the complex thus formed is not sufficiently stable to be recognized in solution. When the number of water molecules is other than four or six, however, this theory no longer offers a satisfactory explanation, since these are the only numbers which are generally recognized as coördination values. In the realm of double salts the situation is much the same. Carnallite, for example, has been given the formula(168) $MgCl_3K$, but no attempt is made to account for the six molecules of water which are present.

It is most striking to note that the coördination theory is able to explain most of the compounds which are known to exist in other than the solid state, while it fails entirely with a great many which are not known in a state of molecular subdivision. This at once suggests that the forces responsible for such compounds may differ from ordinary primary and secondary valence forces. In fact, there seems to be no reason for assuming that two or more different kinds of molecules can not possibly solidify together according to the same laws that govern the solidification of a single kind. If this is the case, there is no more reason for attempting to explain the phenomenon according to some theory of valence than there is similarly to explain the solidification of a single species. It is recognized that the forces which bind atoms together to form molecules are doubtless of the same ultimate nature as those which bind molecules together to form crystals, but the magnitude and effect is sufficiently different to justify a distinction.(169)

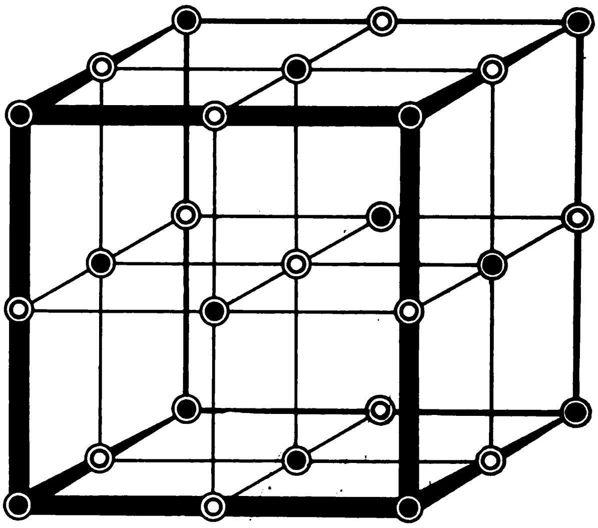

Fig. 94. The Sodium Chloride Lattice. The white-centered circles represent Na and the black-centered Cl, or vice versa

The Crystal Structures of the Various Chemical Types

Of those compounds which have the strict crystal structure requirements of the ethylene bromide class mentioned, only a few have been completely analyzed. The best example of this class is hexamethylenetetramine,(170) $C_6H_{12}N_4$. The crystals of this substance are made up of molecules, which are arranged in the form of a body-centered cube. While the laws of scattering are not well enough known at present to establish the exact parameters of the carbon and nitrogen atoms, it is quite evident that the closest approach of any two atoms in different molecules is greater than the distance between those of the same molecule. This grouping together of the atoms to form well defined molecules within the crystal satisfies the foregoing requirements imposed upon this type of compound. While a large number of other organic compounds have been studied, some doubt has been thrown upon the reliability of the results of these analyses,(171) and they will not be considered here.

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(167) Schwartz and Bass, op. cit., p. 36.

(168) Schwartz and Bass, op. cit., p. 14.

(169) For a discussion of crystal forces see Langmuir, *J. Am. Chem. Soc.*, *38*, 2221, (1916).

(170) Dickinson and Raymond, *J. Am. Chem. Soc.*, *45*, 22, (1923).

The atomic environment in the sodium chloride type of compound is well known.(172) As can be seen in Fig. 94, each atom of one kind is surrounded by six atoms of the other kind, which mark the points of an octahedron with the first atom at the center. This arrangement is the one most frequently found in highly polar compounds from two univalent or two divalent elements. It includes most of the alkali halides, the oxides and sulphides of the alkaline earths, etc. It is to be noted that each atom is related in exactly the same way to six atoms of the other kind. The chloride, bromide, and iodide of caesium crystallize in the body-centered cubic lattice. In this case, each atom is surrounded by eight atoms of the other kind, located at the corners of the cube of which it is the center. In the zinc sulphide lattice we find an atom of one kind located at the center of a tetrahedron made up of four of the other; hence, an atom of one kind has the same relationship to each of four of the other kind. Of this general type of compounds two types will be mentioned which are made up of two elements, one having twice the valence of the other. The lattice of cuprite, Cu_2O, (Fig. 95) has a body-centered cubic arrangement of O atoms, with the Cu atoms located one-fourth of the way along on alternate ends of the body diagonals. This places each Cu atom at the center of a tetrahedron of O atoms, while each O atom is midway between the two Cu atoms. Silver oxide has the same arrangement. In calcium fluoride (Fig. 96) the divalent metal has a face-centered cubic arrangement, with the univalent element one-fourth the way along on each end of the body diagonals. This places the calcium in the center of a cube of fluorine atoms, and the fluorine at the center of the tetrahedron of calcium atoms. The dioxides of uranium, thorium, and cerium have been found to have the same arrangement.

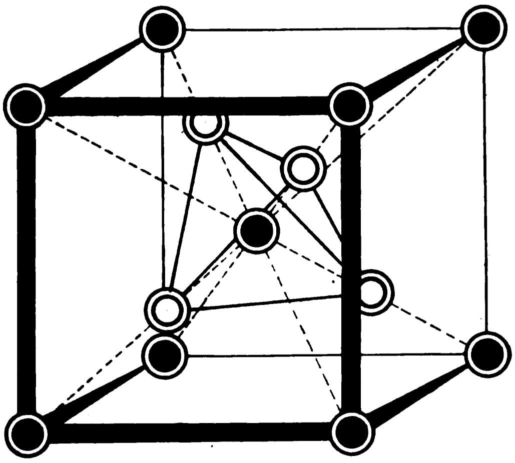

Fig. 95. The Cuprite Lattice. The white-centered circles represent Cu and the black-centered represent O

The chemical properties of this class of compounds impose no molecular association of the atoms in the crystal, and nothing is found in the crystal structure to indicate any such molecular formation. In all of the score or more compounds of this type which have been studied by the x-ray, not a single exception to this generality is known. An apparent exception might be seen in the structure of tin tetraiodide, the crystals of which are made up of SnI_4 molecules. This compound, however, is highly nonpolar, and would naturally fall into the ethylene bromide class.

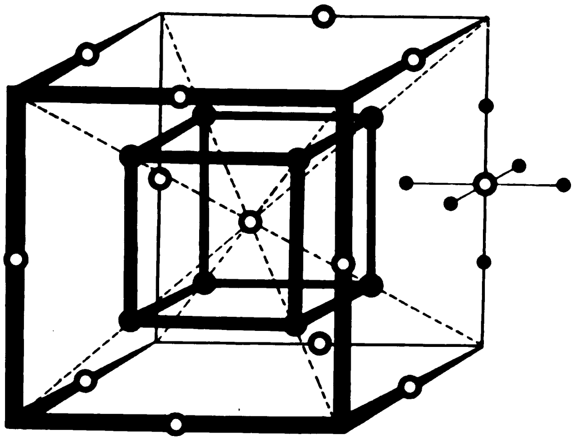

Fig. 96. The Calcium Fluoride Lattice. The white-centered circles represent Ca and the black-centered circles represent F. To make the diagram represent the K_2SnCl_6 lattice, the black-centered circles represent the K and the white-centered circles represent the Sn of the $SnCl_6$ radical. The Cl atoms are shown grouped about the Sn atom at the extreme right, only. These small black dots are not to be considered a part of the CaF_2 lattice

Of all the compounds whose crystal structures have been determined, the most significant from the standpoint of valence are the complex Wernerian compounds. The environments of the atoms in these compounds represent a combination of those found in the two preceding groups. In potassium chlorostannate the potassium and tin atoms have the calcium fluoride arrangement. Surrounding each tin atom are six chlorine atoms placed less than one-fourth of the way along the edges of the cube. An exactly similar structure has been found for $(NH_4)_2SnCl_6$, $(NH_4)_2PtCl_6$, K_2PtCl_6, $(NH_4)_2SiF_6$, $NiCl_2 \cdot 6NH_3$, $NiBr_2 \cdot 6NH_3$, and $NiI_2 \cdot 6NH_3$. The exact parameters of the coördinated atoms and molecules vary slightly, but they are always more than 0.20 and *less* than 0.25.(173) Thus the coördinated radicals, be they chlorine atoms or ammonia molecules, are placed around the central atom in an octahedral arrangement, and are closer to it than to any other atom in the crystal. They form a definite group in the crystal just as the molecules did in the compounds of the ethylene bromide class. These groups are arranged so that during solution they are free to combine with any two of the eight univalent ions which surround it, as was the case with the Ca in CaF_2.(174)

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(171) Wychoff, "The Structure of Crystals," p. 369. Chemical Catalog Co., 1924.

(172) The crystal structure of the various compounds mentioned in this part of the serial are taken from Wychoff, op. cit., (See also International Critical Tables).

(173) The parameter of Cl in K_2PtCl_6 has been reported to be about 0.16. This figure would seem unlikely. Cf. Wyckoff, op. cit., p. 344.

In this connection, it is important to note that the atoms which are in coördination positions are bound more firmly and more closely to the central atom than they are to any other. This is our only means of distinguishing in the solid state these groups which are likely to be able to remain intact during phase changes of the substance. Failure to take cognizance of this distinction has led to some peculiar conclusions. One author(175) has pointed out that since each atom is surrounded by six of the other kind in sodium chloride, the coördination number of sodium and chlorine is six; while in potassium chloroplatinate, each potassium atom is surrounded with twelve chlorines, so its coördination number is twelve! Such loose applications of the term has the effect of rendering it meaningless. The numbers four and six were originally chosen as coördination numbers upon purely experimental grounds. These two numbers are sufficient to explain the large majority of typical Wernerian complexes, but there would seem to be no *a priori* reason for arbitrarily excluding others when the need for them arises. For example, there are numerous oxyacids containing three oxygen atoms and there seems to be no essential difference between these and others containing four or six atoms. If it is assumed that atoms or groups in coördination positions are arranged symmetrically in space about the central atom, we are limited at once to those numbers 2, 3, 4, 6, 8, 12, etc., which are capable of such symmetrical arrangement. The extention of the theory to include these values seems to be well justified.

With coördination values greater than three it is necessary to assume that the coördination positions have spacial rather than plane symmetry, in order to account for the low number of isomers. Thus, no isomers of groups containing four coördination positions are known when two of the positions are filled with one kind of atom, and two with another. A tetrahedral arrangement of these atoms accounts for such lack of isomerism, while a plane arrangement would not. This seems to indicate that the symmetry is spacial. At the same time, it was noted that Pt and Cl atoms in the K_2PtCl_4 crystals were in one plane. This descrepancy may be explained by assuming that the plane arrangement is not stable or rigid in a state of ionic or molecular subdivision. It seems likely that a great many of the salts of the oxyacids such as sulphates have such a plane arrangement in the crystal, since this permits the oxygen atoms all to be the same distance from the sulphur without holding equivalent crystallographic positions. This is the most obvious conclusion in regard to many compounds of low symmetry. At present, however, it seems that such a plane arrangement is to be considered in the nature of a compromise and unstable in solution.

In potassium chloroplatinite, K_2PtCl_4, the platinum and chlorine atoms lie in the same plane, if the suggested structure is correct. Potassium chloropalladite has the same structure. While this condition of affairs is rather unexpected, it is not to be regarded as a serious discrepancy. The important criterion, that the coördinated groups be closer to the central atom than to any other, is fulfilled. Several complex cyanides of the potassium zinc cyanide type have been studied also. In $K_2Zn\ (CN)_4$ the cyanide groups are tetrahededrally arranged about the zinc atom as would be expected (Fig. 97). The $Zn(CN)_4^{--}$ groups can be regarded as the units, which together with the two K^+, make up the crystal. As can be seen from the diagram, the CN groups are closer to the zinc atoms than they are to the potassium. Considerable interest is attached to this grouping because of its close relationship to certain other salts, as will be seen later.

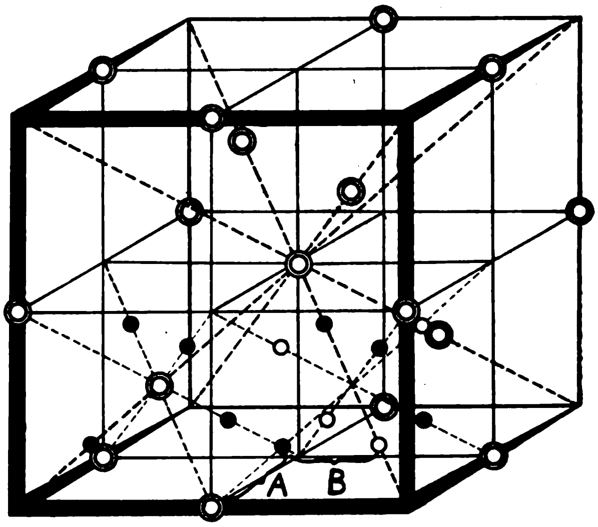

Fig. 97. The Potassium Zinc Cyanide Lattice. The zinc atoms are represented by large white-centered circles, the K atoms by small circles, and the mean position of the C and N atoms by small black dots. K and CN groups are shown in the lower front octants only. The distances A and B have a ratio of about 43 to 50

The structures of only a few salts of the oxyacids have been determined. With those which have, it is clear that the acid radicals act as units in the crystal, and the oxygen atoms are grouped symmetrically about the acid-forming element. In sodium nitrate and calcite ($CaCO_3$), the NO_3 and CO_3 groups are in the form of equilateral triangles, with oxygen atoms at the corners and the other atoms at the center. Silver molybdate, Ag_2MoO_4, has the same structure as $K_2Zn(CN)_4$ with Ag, Mo, and O replacing K, Zn, and (CN), respectively. This serves to support the view that there is no essential difference in structure between chloro- and oxyacids.

The crystal structure of spinel $MgAl_2O_4$, is so unexpected as to appear almost doubtful, although the x-ray data seem to be perfectly definite. Its structure is the same as that of Ag_2MoO_4 and the oxygen atoms have the same parameters as nearly as can be determined. This seems to throw the magnesium into the rôle of the acid-forming element, since the oxygen atoms are closer to it than to the aluminium atoms. No suggestions as to the cause or significance of this anomaly can be made at present. Many more data upon this type of compound are needed.

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(174) This statement is worded in terms of the ordinary picture of dissociation. It may be assumed to be literally true in the case of the vapor of a volatile substance.

(175) P. P. Ewald, "Kristalle und Roentgenstrahlen," p. 211 et. seq. Julius Springer, (1923).

Unfortunately, no one seems to have determined the crystal structure of any compounds which are known only in the solid state and which cannot be explained by current theories of primary and secondary valence.* The alums have received a great deal of attention, but the parameters of the water molecules have not been determined. It was predicted a number of years ago on theoretical grounds that many of the complex minerals, such as those of the polysilicic acids, would be found to contain molecules of the oxides of the metals as the units within the crystal.(176) $(K_2O) \cdot (Al_2O_3) \cdot (SiO_2)_6$ was cited as an example. Thus far, no data have been published which support this view. In fact, no compounds of this type have been studied. Even the crystal structure of potassium dichromate might prove to be an entering wedge to this type of compounds.(177) At least it might offer a clue to the explanation of spinel, the only salt of a polyacid so far studied by x-ray methods.

The Chemical Significance of Crystal-structure Data

The preceding treatment has had to do chiefly with the correlation of crystal-structure data, as determined by x-ray diffraction methods, and the existing theories of primary and secondary valence. Such a treatment would be incomplete without some critical note of the absolute significance of these data at the present status of our information regarding the laws which control crystal habit. A previous article in this series(178) has been devoted to a study of the sizes and shapes of atomic and ionic domains. For the same type of chemical combination (*i.e.*, ionic, electron sharing, etc.) we may assume the atoms or ions to have an approximately constant size as was assumed in that article. In regard to shapes, the treatment involved the assumption that the packing shapes of the ions and atoms could be determined by the symmetry of the crystal and the environment in which the ions or atoms were found. Of necessity, this treatment was limited to the crystals of the elements and binary compounds which have high symmetry. As the multiplicity of crystal forms and the environments in which a single atom or ion may occur is considered, we are forced to the conclusion that many compromises between environment and packing shape are necessary. It is certain that a single radical may appear in many crystal forms. SO_4, which is supposed, on the basis of Wernerian theory, to have tetrahedral symmetry, occurs in compounds in all six of the crystal systems. In cases like monoclinic Na_2SO_4, there would seem to be nothing inherent in the shape of the positive ions to distort such a tetrahedral SO_4 from its preferred cubic symmetry. It may be that the structure assumed represents a compromise between the natural shape of the radical and the necessary close packing of the atoms in the crystal as a whole. There is at present no way at all of estimating the relative importance of the various factors which decide the shape of a radical in a particular crystal, nor can we be sure that the ions which compose a given radical have the same packing shape in each of two different forms of the radical.

In the coördination compounds which have been considered here, of the K_2PtCl_6 type for example, it was found that the chlorine atoms are arranged about the platinum in the form of an octahedron, just as Werner thought they were. It is very much of a question, however, whether they are so arranged because the crystal is cubic, or whether the crystal is cubic because they are so arranged! It is not to be considered that the high symmetry of the crystals we have considered is entirely accidental. There is no doubt that they were chosen in most cases for analysis because of their high symmetry. Therefore, the data here submitted are not random data, and must not be rated as such.

In this presentation a great deal of importance has been attached to the fact that in nearly every case the coördinated groups or atoms were closer to the central atom than to any other atom in the crystal. This condition held so generally that it seems to be of significance, even when considered most critically. However, it must be recognized that this condition can be considered of absolute value only when modified by a fairly accurate idea of the relative packing-radii of the atoms involved. Thus, if, as has been assumed by Lande, the lithium ion has a negligible packing-radius, we should hardly expect that it would be farther removed from the center of the chlorine atoms than is the platinum atom in the corresponding lithium chloroplatinate. Perhaps a knowledge of the packing-radii of the atoms involved would explain away the difficulty in the case of spinel. At any rate, we shall not be in a position fully to appreciate the entire chemical significance of the environment of atoms in crystals until we are so familiar with the laws controlling that environment that we are in a position to predict the crystal structure of a compound from a consideration of its other properties. That time is very far off.

(To be continued)

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*Since this was written, an article by Steele and Davey in the August, 1929, issue of *J. Amer. Chem. Soc.*, gives the crystal structure of tri-calcium aluminate. It is evident from the crystal structure that this compound is neither an ordinary ionic compound nor a coördination compound. It is believed to represent an entirely new type of chemical combination which has been named "mixed ionic." This will be described in detail in a later installment of this series.—Ed.

(176) Langmuir, *J. Am. Chem. Soc.*, *38*, 2241 (1916).

(177) For the Wernerian conception of the polyacids see Schwartz and Bass, op. cit., p. 39.

(178) Davey, General Electric Review, *29*, 274, (1926).

The Electrification of the Mexican Railway

PART III

By J. B. COX
Transportation Engineering Department, General Electric Company

IN May, 1928, the electrification was extended from Cordoba to Paso del Macho, 18 miles farther south, making the total electrification 64 route-miles. The trolley construction on this last extension was the same as on the Cordoba extension, except that only a single 500,000-cir. mil copper feeder was used between Cordoba and Potrero and no positive feeder at all from the substation to Paso del Macho.

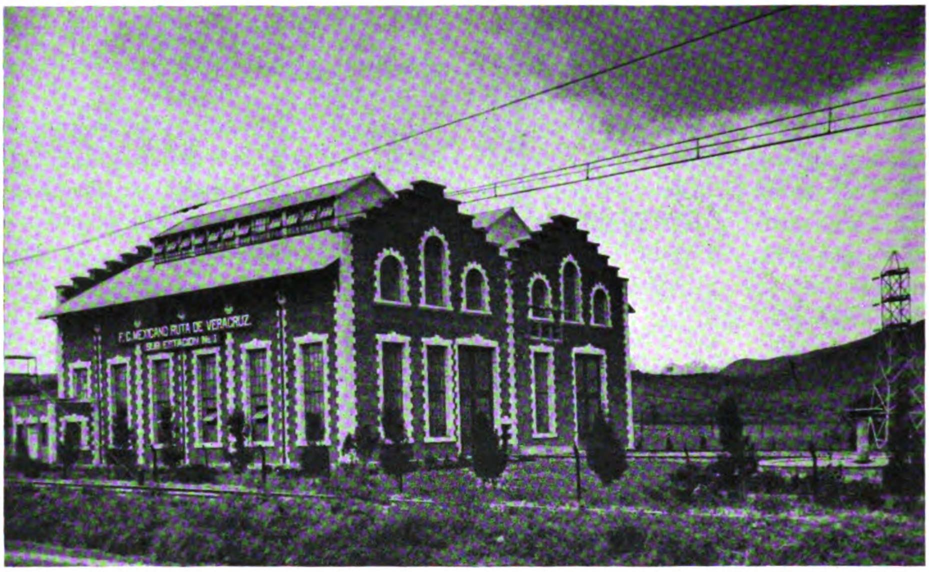

Fig. 15. Exterior of Maltrata Substation Equipped with Two 3000-kw. 3000-volt Motor-generator Sets

Non-ferrous materials were used for hangers and span wires and a copper-clad copper messenger on the last extension, as this section is nearing the seacoast, and it seemed advisable to use such material where steam locomotives are expected to operate at all frequently under the wires.

Substation Equipment

The original substation, located at Maltrata, contains two 3000-kw. 3000-volt d-c. three-unit synchronous motor-generator sets for supplying power to the original 29.5 miles electrified.

Power is purchased from the Puebla Tramway Light & Power Company at 42,000 volts, 60 cycles. Ample provision is made for housing all of the substation equipment, the transformers and high-tension switching occupying about one-half the building. The other half of the station is occupied by the motor-generator sets and switching equipment; each motor-generator set is protected by a high-speed circuit breaker and each of the outgoing feeders has the same protection.

With the extension of the electric zone to Paso del Macho, a second substation was installed at Potrero, approximately 39 miles from Maltrata and 8.5 miles from Paso del Macho. The power demands for this portion of the line, however, are much lighter on account of the easier grades, so this station contains two 1500-kw. units which are similar in other respects to the original equipment. This station is also supplied from the 42,000-volt three-phase 60-cycle circuit which forms a part of the power company's network.

Each substation building provides the necessary space and foundations for a third unit when required. The equipment used is standard, being similar to that supplied the Chicago, Milwaukee & St. Paul, the Spanish Northern, and the Paulista Railways.

Fig. 15 shows the exterior of Maltrata substation and Fig. 16 an interior view of the same, showing the motor-generator sets and high-speed circuit breakers, while Figs. 17 and 18 are other interior views of the Potrero and the Maltrato substations.

Electric Locomotives

The initial motive power equipment for the Orizaba-Esperanza section included ten locomotive units suitable for handling both passenger and freight service. These are of the twin-geared 6-motor articulated truck type capable of operating at a maximium speed of 40 m.p.h. and provided with equipment for regenerative electric braking.

The cab is of the box type mounted on two equalizer frames which in turn are carried upon three two-axle trucks. The motors are twin geared to each axle through cushion-type gears.

The motors are designed for 1500 volts per commutator; two being connected permanently in series. An unusual feature of this locomotive is the provision for removing the motor wheels and axle from any of the trucks without lifting the cab. These units are so constructed that the wheels, axle and motor can be dropped into the pit after first disconnecting the motor leads, or the wheels and axle may be taken out alone by propping up the motor and side frames.

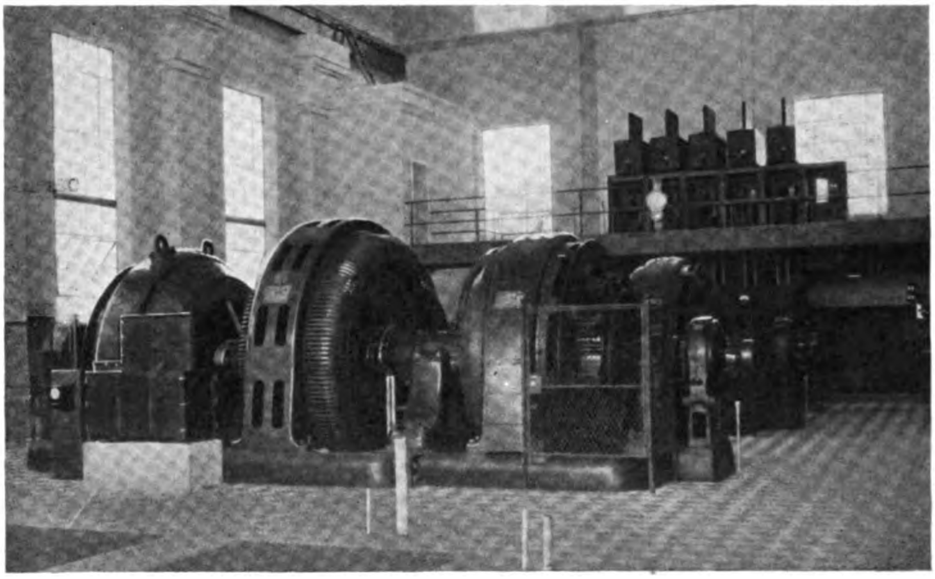

Fig. 16. Interior of Maltrata Substation, Showing Two 3000-kw. 3000-volt Motor-generator and High-speed Circuit Breakers

The auxiliary machinery consists of a 3000/1500-volt dynamotor with a 65-volt control generator mounted on the shaft extension; a 1500-volt regenerative exciter set; two 1500/3000-volt motor-driven blowers and two 1500/3000-volt air compressors. The two blowers and the two compressors normally operate in series across the 3000-volt circuit with their mid points connected to the mid point of the dynamotor for equalization. The regenerative exciter set operates from the 1500-volt circuit of the dynamotor. The scheme of operation provides a means for operating one compressor or one blower from the 1500-volt dynamotor bus in case of failure of the other unit. This arrangement also permits operating the compressors and blowers in case the dynamotor fails.

The locomotives are equipped with electro-pneumatic control for non-automatic multiple unit operation. A master controller in the engineman's cab at each end is arranged to give a total of 31 accelerating steps, distributed through the three groupings of the motors, a full-field and two reduced-field running steps with each of the three combinations. This gives a total of nine running points which, for a given tractive effort of 50,000 lb. and 2700 line volts, corresponds to a speed range of from approximately 5½ to 26½ m.p.h., and correspondingly higher speeds at lighter loads.

The main motor circuits are protected by a high-speed circuit breaker which also serves as a line breaker as well as to give overload and short-circuit protection.

Current is collected from overhead slider pantographs, one of which is located at each end of the cab roof. These collectors have a range of from 15 ft. 5 in. to 24 ft. above the top of the rail. Fig. 19 shows a view of one of the locomotives and Fig. 20 one of the electric locomotives hauling a passenger train.

With the extension of the electrification from Orizaba to Paso del Macho, additional motive power was required and for this purpose two locomotives, duplicates of the original design, were used.

Table XXIV gives the electrical and mechanical data on these locomotives and Fig. 21 gives a dimensioned outline drawing.

Fig. 22 and 23 are included because of the general interest in showing the type of steam locomotive formerly in use.

Transmission Line

A 42,000-volt transmission line 17 miles in length was constructed from the Tuxpango hydroelectric generating station of the Puebla Tramway Light & Power Co. to the Maltrata substation. Twin lines of No. 1/0 aluminum cable are supported on steel A frames with anchor towers at proper intervals.

A similar line of approximately the same length, but with only a single set of conductors, is now under construction from the same generating station to the new substation at Potrero. In the meantime the power company's line to Vera Cruz, which the new line

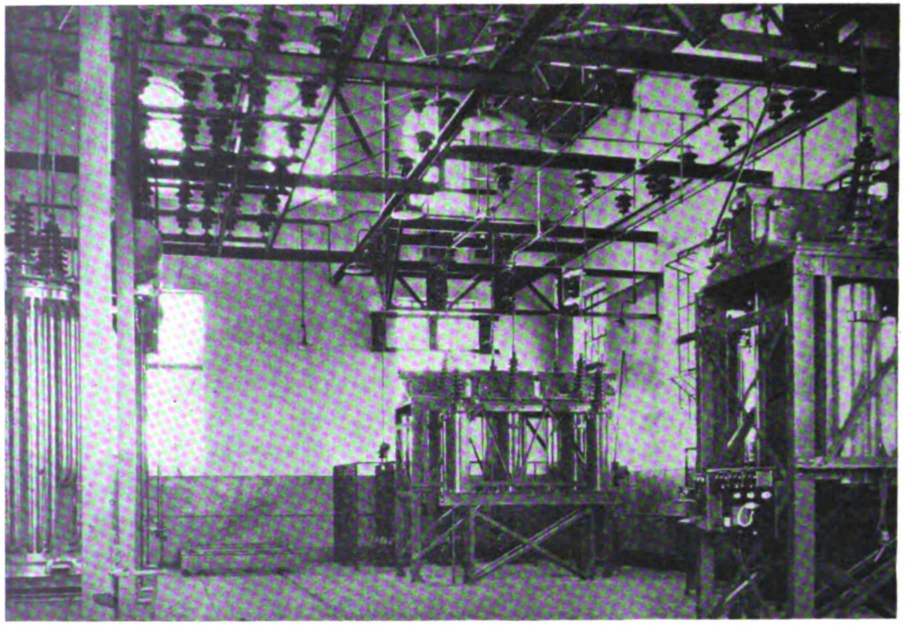

Fig. 17. Interior of Potrero Substation, Showing High-tension Switching Equipment

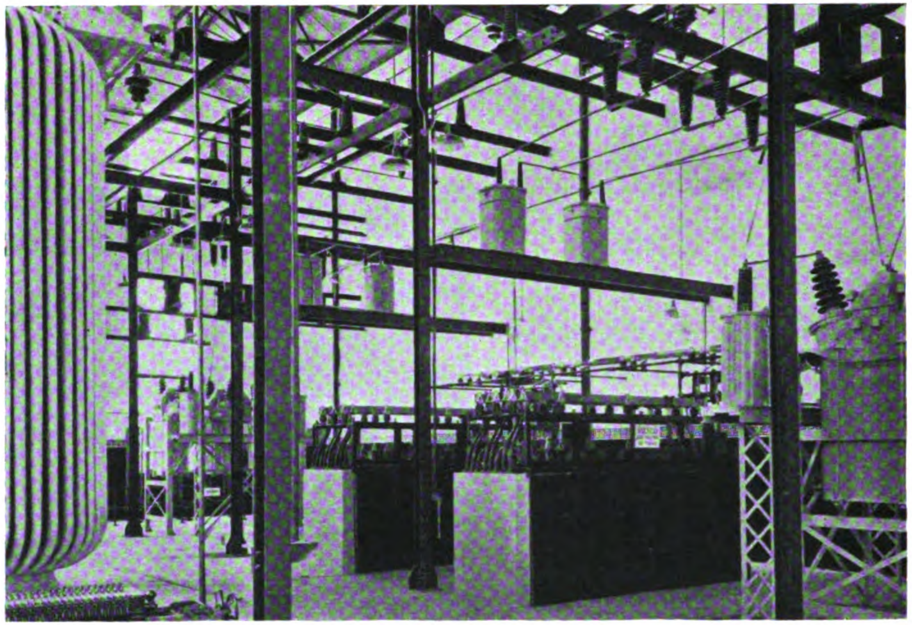

Fig. 18. View in Transformer Room, Showing Oil-circuit Breakers and Buses

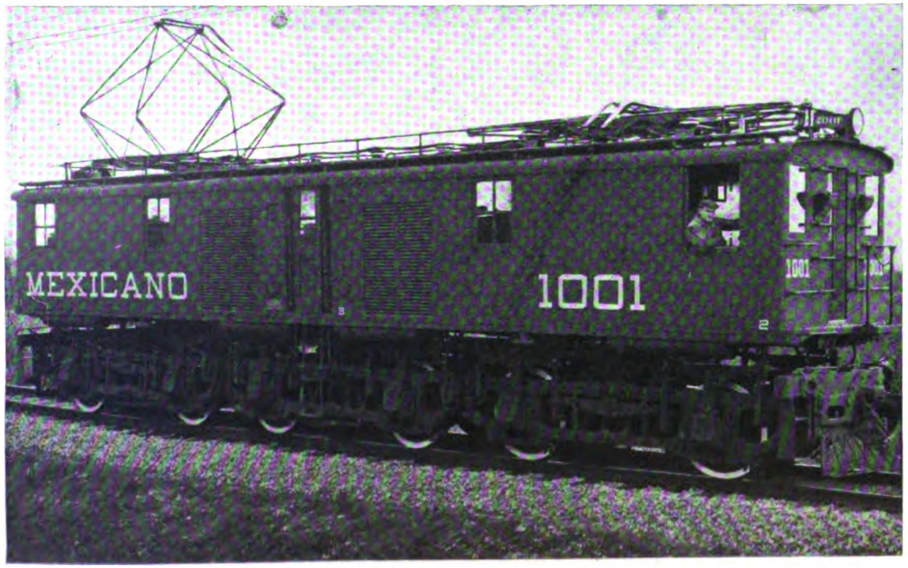

Fig. 19. A 3000-volt 150-ton Six-motor Locomotive for Either Freight or Passenger Service

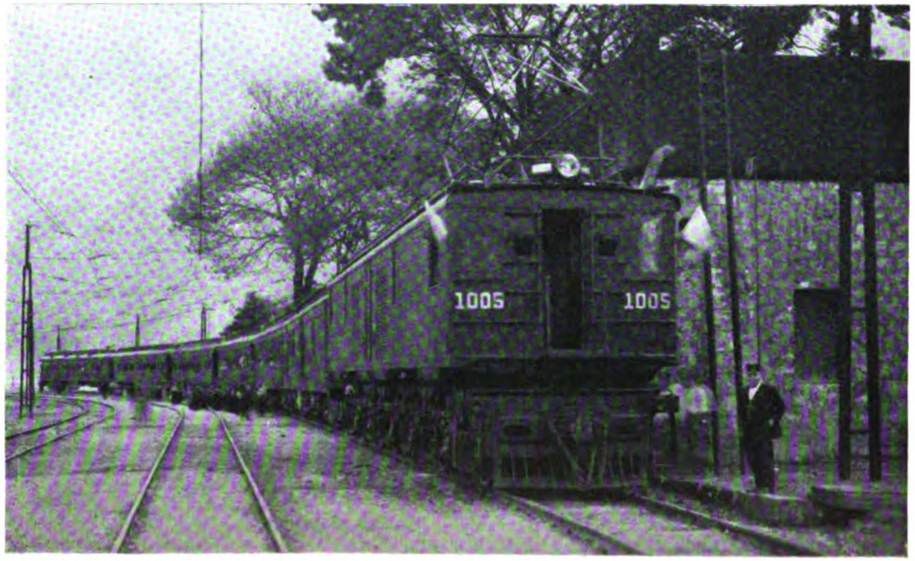

Fig. 20. Passenger Train with 150-ton 3000-volt Locomotive at Maltrata Station

parallels, is being used and switching arrangements are provided in the substation for reciprocal use of the lines when desirable.

Electrical Operation

The Orizaba-Esperanza section has now been in complete operation electrically since January, 1925, thus making available the records for four full years of operating data and costs

The great reduction in business resulting from the unsettled conditions caused by the disturbances of 1924, as well as new labor agreements and increased wages, had tended to make direct comparisons of operating costs look less favorable than they really were. A decrease in the tonnage to be hauled reduces operating costs to an extent, but unfortunately not nearly in the same proportion, and the capital charges remain practically the same. On the other hand, increased wages and higher costs of fuel and materials usually tend to make electrification comparatively more profitable.

The operation has been very satisfactory and successful throughout. No serious difficulties have been encountered with any portion of the equipment. This may fairly be measured by reference to the complaint bill for the usual guarantee period, which was less than three thousand dollars ($3,000.00).

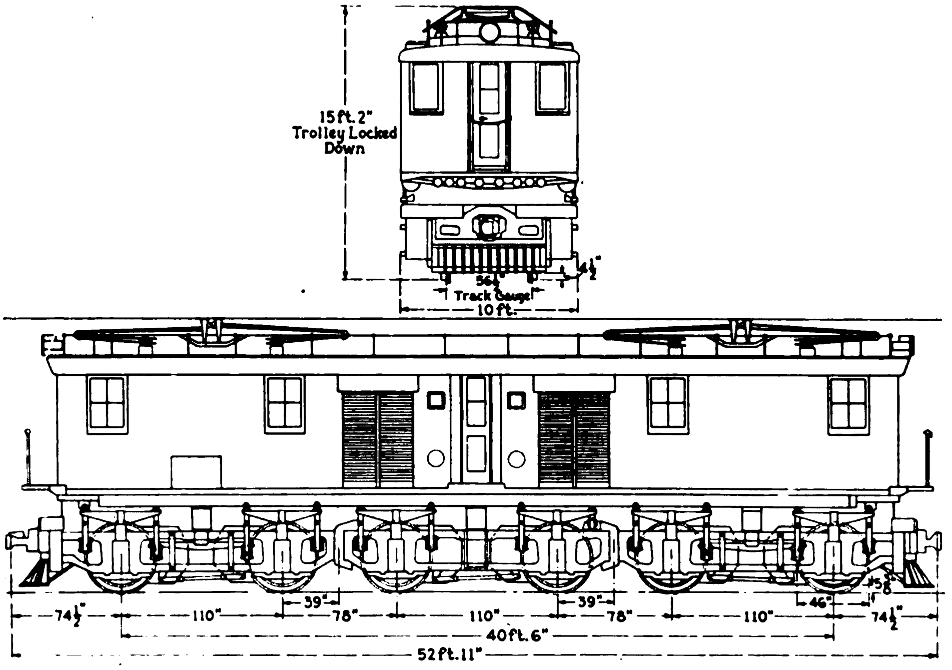

Fig. 21. 150-ton 3000-volt D-c. Locomotive for Mexican Railway. Outline and Dimensions

TABLE XXIV

ELECTRICAL DATA	
Nominal voltage of system	3000 v. d-c.
Tractive eff., 1 hr. blown (3000 v.)	54,000 lb.
Speed at 1-hr. rating, full field	19 m.p.h.
Total horsepower, 1 hr	2736
Tractive eff., continuous 3000 v. full field	48,500
Speed at continuous rating, 3000 v.	19.5 m.p.h.
Total horsepower, continuous	2520
Number of motors	6
Type of motors	GE-278-A-1500/3000 v.
Gear ratio	90/18
Tractive eff. at 30 per cent tract. coef.	92,700 lb.
MECHANICAL DATA	
Track gauge	4 ft. 8½ in.
Wheel arrangement	0 4 4 4 0
Diameter of drivers	46 in.
Number of driving axles	6
Total wheel base	40 ft. 6 in.
Max. rigid wheel base	9 ft. 2 in.
Width overall	10 ft. 1½ in.
Height over trolley locked down	15 ft. 2 in.
Length inside knuckles	52 ft. 11 in.
WEIGHTS	
Total weight on drivers	309,000 lb.
Dead weight per axle	12,150 lb.
Elec. and air brake equipment	135,000 lb.
Mechanical equipment	174,000 lb.

The general performance of the equipment may best be judged by the costs of maintenance, a fair average of which is given herein.

During the months of March and April, 1928, the traffic over the Orizaba-Esperanza section reached a new maximum, which was somewhat in excess of that for steam operation which had been attained during the months of September and October, 1921, and which was used as a basis in the original study. This offered a favorable opportunity for comparing actual results of electrical operation with that for steam operation, as well as to check the estimates in the report leading to the electrification.

Detailed tabulations of the operating records for March and April, 1923, with electrical operation were prepared for comparison with similar records as used in the report for September and October, 1921, with steam operation, as shown in Table XXV.

A summary of this comparison will be found in Table XXVI.

Briefly stated, the 10 electric locomotives during March and April handled 36 per cent more ton-miles than were handled by more than double the number of steam locomotives during September and October, with 8 per cent less trains and in 40 per cent less train-hours on the road, and at 50 per cent of the corresponding total cost of steam operation for 26 per cent less tonnage handled. A saving of $67,102 was thus accomplished for the two months, or at the rate of $402,612 per year; this alone represents a return of more than 15 per cent on the gross cost of the electrification, including electric locomotives. However,

TABLE XXV

COMPARISON OF TRAFFIC DURING THE MONTHS OF MARCH AND APRIL, 1928, MAXIMUM MONTHS ELECTRICAL OPERATION, WITH SEPTEMBER AND OCTOBER, 1921, MAXIMUM MONTHS STEAM OPERATION

MEXICAN RAILWAY COMPANY—ORIZABA-ESPERANZA DISTRICT

	NORTHBOUND		SOUTHBOUND		TOTAL OR AVERAGE		PER CENT	
	Steam	Electric	Steam	Electric	Steam	Electric	Increase	Decrease
Passenger Service								
Number of trains	89	122	87	122	176	244	38	..
Number of cars	640	949	609	959	1,249	1,908	52	..
Number of tons	21,595	41,642	20,048	41,943	41,643	83,585	100	..
Number of train-hours	255	244	174	223	429	467	9	..
Average No. trains per day	1.46	2.00	1.43	2.00	2.89	4.00	38	..
Average No. cars per train	7.19	7.78	7.00	7.86	7.10	7.82	10	..
Average tons per train	243	341	230	344	237	343	..	..
Average hours per train	2.87	2.00	2.00	1.83	2.44	1.91	..	..
Per cent increase tons per train	...	40.32	...	49.56	...	44.72	..	..
Per cent decrease time per train	...	30.31	...	8.50	...	21.72	..	..
Freight Service								
Number of trains	533	404	387	363	920	767	..	16
Number of cars	4,086	5,448	3,903	5,484	7,989	10,902	37	..
Number of tons	175,625	195,357	88,701	137,095	264,326	332,452	25	..
Number of train-hours	2,656	1,167	1,492	1,084	4,148	2,251	..	46
Average No. trains per day	8.74	6.62	6.34	5.95	15.08	12.57	..	16
Average No. cars per train	7.67	13.48	10.09	15.11	8.68	14.25	64	..
Average tons per train	330	484	229	378	287	433	..	..
Average hours per train	4.98	2.89	3.85	2.99	4.51	2.93	..	..
Per cent increase tons per train	...	46.66	...	65.06	...	50.87	..	..
Per cent decrease time per train	...	41.96	...	22.33	...	35.03	..	..
Freight and Passenger Service								
Number of trains	622	526	474	485	1,096	1,011	..	8
Number of cars	4,726	6,397	4,512	6,443	9,238	12,840	39	..
Number of tons	197,220	236,999	108,749	179,038	305,969	416,037	36	..
Number of hours	2,911	1,411	1,666	1,307	4,577	2,718	..	40
Average No. trains per day	10.20	8.62	7.77	7.95	17.97	16.57	..	8
Average No. cars per train	7.60	12.16	9.52	13.28	8.43	12.70	50	..
Average tons per train	317	451	229	369	279	412	..	..
Average hours per train	4.68	2.68	3.51	2.69	4.18	2.69	..	..
Per cent increase tons per train	...	42.27	...	61.13	...	47.67	..	..
Per cent decrease time per train	...	42.73	...	23.36	...	35.64	..	..

TABLE XXVI

	STEAM OPERATION	ELECTRIC OPERATION	Difference in Amount	Advantage of Electric Operation Over Steam Operation in Per Cent
	1921 Sept. and Oct.	1928 Mar. and Apr.		
Number of trains run	1,096	1,011	85	8% less trains
Number of cars handled	9,238	12,840	3,602	39% more cars
Number of tons handled	305,969	416,037	110,068	36% more tons
Number of train-hours	4,577	2,718	1,859	40% less train-hours
Number of tons per train	279	412	133	48% more tons per train
Number of cars per train	8.43	12.70	4.27	50% more cars per train
Number of hours per train	4.18	2.69	1.49	36% less hours per train
Cost enginemen's wages	$17,982	$14,565	$3,417	19% less cost for enginemen
Cost trainmen's wages	14,222	10,721	3,501	21% less cost for trainmen
Cost fuel oil or power	36,965	31,140	5,825	16% less cost for fuel
Cost locomotive repairs	59,208	5,969	53,239	90% less cost for repairs
Enginehouse expense	3,391	1,945	1,446	42% less cost for enginehouse
Lubricants	2,776	92	2,684	97% less cost for lubricants
Substation operation	....	2,154	2,154	
Trolley maintenance	....	856	856	
Total cost items affected	$134,544	$67,442	$67,442	50% less cost for total

this amount does not represent the actual saving, since the cost of all classes of labor had considerably increased during 1922 and 1923, so that it is necessary to adjust the costs of the steam operation to have them indicate what they would have been if the increased traffic of March and April had been handled by steam and at the higher rate of wages, as was done by the electric locomotives.

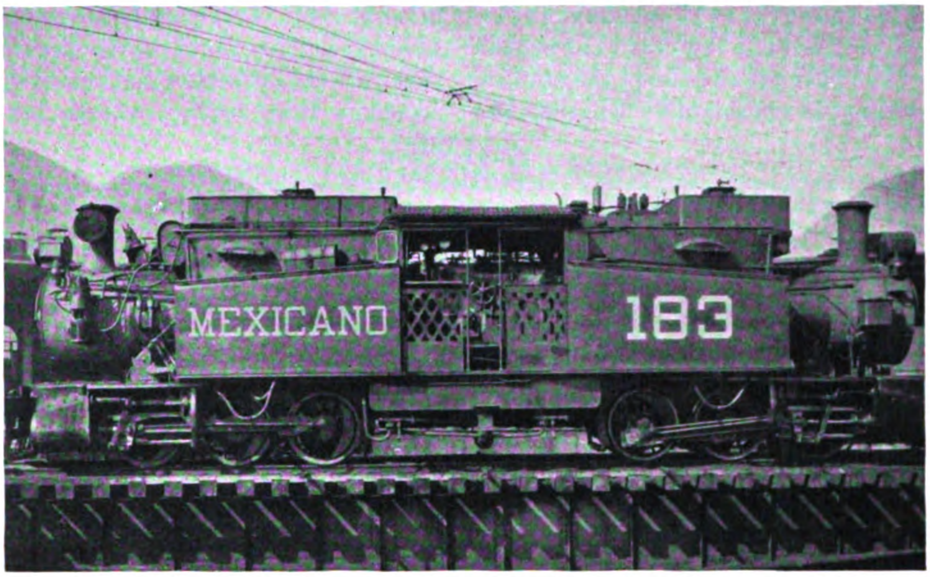

Fig. 22. One of the 150-ton Firley-type Double-ended Oil-burning Steam Locomotives Formerly Used in the Electric Zone

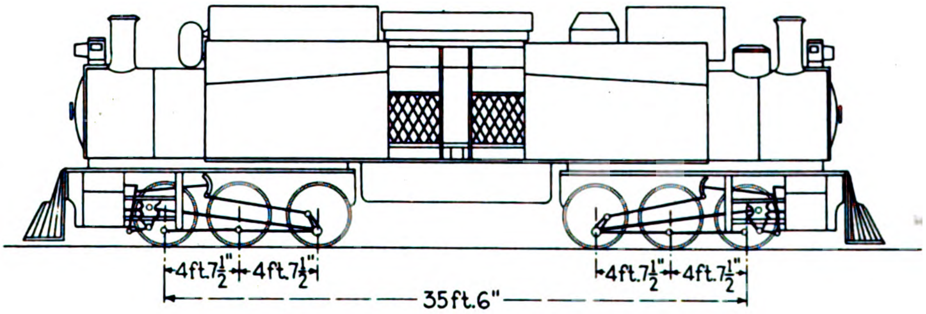

Fig. 23. Dimensions of Locomotive Shown in Fig. 22

Between October, 1921, and the end of 1923, and before the electrification had been completed, new contracts were made with practically all labor involved in these operating costs, under the terms of which the rates of pay were materially increased. Enginemen's and trainmen's wages were increased on an average of about 42 per cent, which higher rates were in effect in March and April, 1928. These increases are given in Table XXVII.

TABLE XXVII

	1921	1928	Per Cent Increase
Enginemen per round trip	$6.00	$8.88	48.0
Firemen per round trip	2.88	4.44	54.1
Conductors per round rip	5.50	7.20	30.9
Brakemen per round trip	5.50	7.20	30.9

The wages of mechanics and others employed in the repair and care of locomotives were also proportionally increased; but last year, and during the previous year, considerable reductions were made in this class of labor, in fact, to such an extent that no adjustment for wages in cost of repairs was considered necessary.

The average price paid for fuel oil during the months of September and October, 1921, was $1.09 per barrel, but the price paid for it in March and April is given as $1.29, an increase of 18 per cent.

In adjusting the cost of steam operation for September and October, 1921, for the 36 per cent increase in traffic, it was considered inaccurate to assume that the cost would increase in the same proportion, since the number of trains required to handle the traffic are almost entirely determined by the north-bound, or uphill traffic, which exceeded the south-bound by 32 per cent during March and April. It is also possible to take considerably heavier trains down than up the mountain grade.

The adjustment for increased traffic was consequently made on the basis of the increased number of steam trains that would have been required to handle the north-bound business.

The passenger trains running north in March and April numbered 122 as against 89 in September and October, an increase of 33 trains.

The freight tonnage hauled north for the same period was 195,357 and 175,625 tons respectively, an increase of 19,732 tons. At an average of 330 tons per train, which is the exact record for the steam locomotives, 60 additional freight trains would have been required to handle this excess freight tonnage, making a total increase of 93 trains, or 14.95 per cent. On an already congested single-track line with infrequent passing tracks, a 14.95 per cent increase in the number of trains would ordinarily considerably lengthen the time per train, and consequently increase the cost of wages and fuel; but since the enginemen and trainmen are paid by the trip, if made in ordinary time, and the run being unusually short, no allowance was made for this item. It was considered conservative to assume that all other costs of the items listed would be increased in approximately the same proportion as the number of trains operated, *i.e.*, 14.95 per cent.

TABLE XXVIII

	STEAM	ELECTRIC	REDUCTION	
	Sept. and Oct.	Mar. and April	Amount	Per cent
Enginemen	$30,991	$14,565	$16,426	53
Trainmen	21,722	10,721	11,001	50
Fuel or power	50,139	31,140	18,999	38
Repair to locomotives	68,059	5,969	62,090	91
Enginehouse expense	3,898	1,945	1,963	50
Lubricants	3,191	92	3,099	97
Substation operation maintenance	....	2,154	....	..
Trolley operation maintenance	....	856	....	..
Total	$178,000	$67,442	$110,558	62

TABLE XXIX

	Steam	Electric	SAVING	
			Indicated	Estimated
Enginemen	$185,946	$87,390	$98,556	$76,538
Trainmen	130,332	64,326	66,006	62,099
Fuel or power	300,834	186,840	113,994	71,790
Repairs to locomotives	408,354	35,814	372,540	304,137
Enginehouse expense	23,388	11,670	11,718	15,105
Lubricants	19,146	552	18,594	13,735
Substation operation maintenance	....	12,924	....	....
Trolley operation maintenance	....	5,136	....	....
Total	$1,068,000	$404,652	$663,348	$522,029

When the costs of steam operation are adjusted on the basis outlined, the direct comparison between steam and electric operation for traffic handled in March and April, 1928, is as shown in Table XXVIII.

In order to compare directly these figures with the estimate in the original study on this subject the costs were placed on a yearly basis, as set forth in Table XXIX.

The above indicated yearly saving of $663,348 in favor of electrical operation is 27 per cent greater than the estimate, but this was readily accounted for by the 36 per cent greater tonnage handled; since any material increase in traffic should increase the savings also, and in a greater proportion. The increase in wages would also increase the savings, because of the increased tons per train and decreased hours per train with electrical operation.

This annual saving represents approximately 26 per cent on the gross cost of the electrification of the Orizaba-Esperanza district; this alone is a very satisfactory result. There are however other more indirect savings which cannot be so accurately segregated, such as wear on wheels and brake shoes, reduction of accidents from broken wheels due to over-heating while braking, which if fully valued would add many hundreds of dollars to the credit of electrical operation.

Perhaps the most valuable unlisted asset in the electrification is the increased capacity of the lines electrified. On March 18th, 5381 tons of freight and two passenger trains weighing 741 tons, making a total of 6122 tons, were hauled from Orizaba to Esperanza, which was a record for the district. The record day with steam operation was October 25, 1921, when 4008 tons of freight and two passenger trains weighing 640 tons, making a total of 4648 tons, were handled; giving 1474 tons or 31 per cent in favor of the electric operation; 14 trains were used in each case.

The total tonnage handled electrically on March 18th, north and south, was 9659 tons and that for October 25, 1921, by steam was 6532 tons. The excess for electric operation was 50 per cent. The electric train-hours were 64.6; and the steam train-hours were

83.4, a reduction of 18.8 train-hours, or 22 per cent with an increased tonnage handled of 50 per cent.

By increasing the train weight to 900 tons (metric), for which the line and equipment are capable, it would be practicable to handle over the present line double the tonnage handled on March 18th with no additional facilities except for locomotives, cars, and power.

The ten locomotives now in service were expected to be sufficient to handle a maximum of 4200 tons or, regularly 3600 tons in addition to two passenger trains per day in each direction between Orizaba and Esperanza.

heavy grade work this item will average between 40 and 50 per cent.

If the cost of the electric locomotives be deducted from the total cost of electrification the savings from electric operation, as shown, would be equivalent to an earning of 47 per cent on the net cost.

The entire 64 miles has been in full operation for about a year, but the records are not yet available for a comparison such as is given for the original electrification; and it will not be possible to have them so accurate as long as the 48 miles on the Vera Cruz end is operated by steam.

TABLE XXX

CLASSIFIED COST OF THE ELECTRIFICATION

District	Orizaba Esperanza	Orizaba Cordoba	Cordoba Paso del Macho	Total	Per Route Mile	Per Cent of Total
Route miles	29.5	16.0	18.5	64		
Substations	$452,725	.....	$234,194	$686,919	$10,733	19.0
Transmission	187,242	.....	75,888	263,130	4,111	7.3
Power distribution	318,233	148,072	167,022	633,327	9,896	17.6
Poles and fixtures	143,778	76,488	65,868	286,134	4,471	7.9
Houses	23,740	1,382	8,486	33,608	525	0.9
Engineering	61,260	6,687	26,578	94,525	1,477	2.6
Other expenses	25,937	927	2,430	29,294	458	0.8
Total	$1,212,915	$233,556	$580,466	$2,026,937	$31,671	56.1
Per route mile	$41,116	$14,597	$31,376	$31,670		
Locomotives including exchange				$1,580,000	$24,687	43.9
GRAND TOTAL				$3,606,937	$56,358	100.0

This maximum was exceeded by 1181 tons, or 28 per cent, on March 18th, and the average tons per day northbound for the month was 3350 tons, but all ten locomotives were used.

The earnings on investment as shown are for the gross investment including the cost of electric locomotives. Had new steam locomotives been purchased these would have been charged as renewals or betterments, and since sufficient new steam locomotives to handle an equal tonnage on a mountain district would cost approximately as much as the electric locomotives, it should be quite proper to deduct the cost of the locomotives from the cost of the electrification.

In the case of the Mexican Railway the cost of the electric locomotives was approximately 46 per cent of the gross cost of electrification, and usually for

Table XXX gives the segregated cost as prescribed by the Interstate Commerce Commission for each of the three sections, and the total costs for the whole electrification. These costs are taken from the official records of the railway company, with the exception of the item for the new transmission line now under construction, and the two additional electric locomotives recently delivered; these are estimated.

The original estimate contained in the report submitted in April, 1921, for the electrification of the entire 64 miles was $4,032,500.00. The original report did not contemplate the building of any transmission line by the railway company, and proposed that the transformers and a-c. switching be of the outdoor type, but included six more locomotive units than have been found actually required at the present time.

(To be continued)

The Testing of Transformers

PART II

CORE LOSS, EXCITING CURRENT, LOAD LOSS, AND IMPEDANCE

By G. CAMILLI
General Transformer Engineering Department, Pittsfield Works
General Electric Company

WHEN a transformer is connected to a source of alternating current, a loss of energy due to the cyclic reversals of the magnetic flux takes place in the iron. This loss of energy is known as the "core loss," and—together with the magnetic induction in the core—is supplied to the transformer by the exciting current.

The correct measurement of this loss is essential, as the loss is in most cases constant or continuous and therefore has a material bearing on the operating costs.

The core loss is a function of the frequency, the voltage, and the voltage wave form.

The frequency and voltage are easily determined with the aid of ordinary instruments; but unless the wave form of the applied voltage is a sine wave, the results will be greater or less than the sine-wave value, which is taken to be the correct value. A peaked wave (form-factor greater than 1.11) gives lower losses, while a flat wave gives higher losses than would a sine-wave voltage.

In general, voltage waves are peaked due to the nature of the load on the generator, as explained later, and the measured loss will be less than that corresponding to the sine-wave voltage. Measured losses as much as 20 per cent below the correct values have often been observed.

The most serious discrepancy is that caused by the distorted wave shape of the exciting current. The generator e.m.f. is made up of two parts, one of which is balanced by the e.m.f. induced by the changing flux, while the other produces the exciting current for the transformer. If the flux be sinusoidal, the e.m.f. induced by it is also sinusoidal. But since the permeability of the material varies with the magnetic induction, the magnetizing current cannot be sinusoidal. The component of the e.m.f. producing current has the same wave form as the current, and it also cannot be sinusoidal. The total e.m.f. of the generator, then, is made up of one component which is sinusoidal and one which is not. Hence it is not sinusoidal. Its shape must vary with conditions and thus it would be useless to attempt to secure a sine-wave voltage in the generator e.m.f. It is evident that the distortion will be less if the iron be magnetized in the region of maximum permeability and the distortion is sure to become appreciable if the flux density is carried too high.

Obviously, therefore, it is impracticable to obtain sine-wave voltage for the commercial no-load tests of transformers, especially for very large transformers, and that consequently suitable methods should be used for the reduction of the tests to a sine-wave basis.

Since wave-shape distortion increases with the degree of loading of the generator, the principle has been recognized that the transformer exciting kilovolt-amperes should be a small fraction of the capacity of the generator used to furnish the excitation; in other words, the generator rating should be of the same order of magnitude as that of the transformer under test.

The general principle of using sufficiently large generators, though good, is impracticable for large units. For example, to test a 20,000-kv-a. transformer would require a 20,000-kv-a. generator; to to test a 60,000-kv-a. transformer would require a 60,000-kv-a. generator, and so on.

Reduction of Core Loss to Sine-wave Basis

For the reduction of core loss to a sine-wave basis the following method may be used: (2)

A small "standard" transformer the core loss of which has been calibrated on pure sine-wave voltage, is usually excited through potential transformers in parallel with the power transformer under test. The voltage is set by a conventional-type (r.m.s.) voltmeter and the actual losses in both the power transformer and the standard transformer are observed. The factor which would convert the observed core loss of the standard unit into its sine-wave value (known from its calibration curves) is used to convert the observed loss of the power transformer to the sine-wave basis.

To secure accuracy by this method it is necessary:

(*a*). That the standard cores have the same kind of steel-sheets as the transformer core, and be excited at approximately the same flux density.

(*b*). That the potential transformers be of sufficiently large capacity and low impedance to avoid introducing distortion due to the exciting current of the standard core.

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(2) It is possible to obtain a more accurate measurement of transformer core losses with the aid of a flux voltmeter regardless of the voltage wave shape. This method however is not yet standardized by the A.I.E.E.

The so-called flux voltmeter, Fig. A, which is utilized in this method, is essentially an average reading instrument consisting of a d'Arsonval type direct-current voltmeter and rectifying equipment. The principle of its application to core-loss measurement is based on the fact that, if the rated excitation voltage is set by this meter at the rated frequency, the maximum flux density in the core corresponds to the rated

Reduction of Exciting Current to Sine-wave Basis

The exciting current may be corrected for wave shape by carrying the core-loss test a little further. After the core-loss correction has been determined, the voltage should be raised until the measured loss is equal to the correct loss. The exciting current read at this voltage is approximately the true sine-wave value. (3)

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sine-wave voltage excitation, even though the actual impressed voltage may be badly distorted, Fig. B.

The maintenance of the correct rated maximum flux density in the core by this means assures that the hysteresis loss of the core will correspond to the rated sine-wave voltage, because hysteresis depends on the maximum flux density.

Aside from hysteresis loss, a core has also eddy-current losses; but while hysteresis varies as a complicated function of the density, the eddy-current loss varies substantially as the square of the effective r.m.s. voltage. When the excitation voltage is set by the flux voltmeter, the desired maximum-flux density and hence the correct hysteresis loss is obtained.

If the voltage wave is distorted, however, the alternating-current r.m.s. voltage as measured by an ordinary voltmeter will be different from the rated voltage and therefore the actual eddy-current loss under test will be different from that corresponding to the rated sine-wave voltage in the ratio:

$$K=\frac{\text{True eddy loss}}{\text{Observed eddy loss}}=\left(\frac{\text{Flux voltmeter reading}}{\text{R.m.s. voltage value}}\right)^2$$

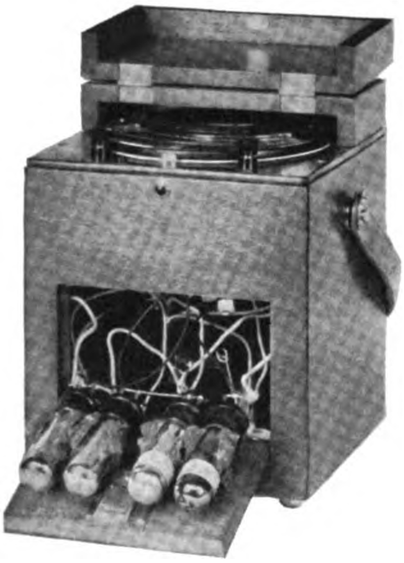

Fig. A. A Flux-voltmeter, with Door Open to Show the Tubes of the Self-contained Rectifier Equipment

A correction has therefore to be applied to the changed eddy-current loss. The method normally used is the following:

If the percentage values of the eddy and hysteresis losses are known for the core density at which the transformer is operated and if the voltage is set by the flux voltmeter, it follows that—

True sine-wave core loss

$$=\text{Observed loss}\times\left(\frac{100}{\text{Per cent hysteresis}+K\times\text{Per cent eddy current loss}}\right)$$

(The eddy-current loss may be assumed to vary between 20 and 25 per cent of the total core loss.)

Example:

Let it be supposed that—

Flux voltmeter reading = 100 per cent rated voltage
Actual r.m.s. voltage = 110 per cent rated voltage

Then

$$K=\left(\frac{110}{100}\right)^2=1.21$$

True core loss watts

$$=\text{Observed watts}\times\left(\frac{100}{\text{Per cent hysteresis}+K\times\text{Per cent eddy current loss}}\right)$$

If the eddy-current loss is 20 per cent and the hysteresis loss is 80 per cent:

True core loss

$$=\text{Observed loss}\times\left\{\frac{100}{80+(1.21\times 20)}\right\}$$
$$=\text{Observed loss}\times 0.96.$$

The correction for error in the eddy-current loss thus amounts to four per cent. If the flux voltmeter were not used at all and no correction applied the observed loss would be about 20 per cent in error (below the true value.) To show that the assumption of a considerably different percentage value of eddy-current loss would not appreciably affect the foregoing result, the following recalculation is made for a percentage of 30 instead of 20.

True loss

$$=\text{Observed loss}\times\left\{\frac{100}{80+(1.21\times 30)}\right\}$$
$$=\text{Observed loss}\times 0.94.$$

Comparing this value with the previous one it will be observed that a 50 per cent variation in the percentage assumed for the eddy-current loss has influenced the final result by only two per cent.

For further information on this method, see "A Flux Voltmeter for Magnetic Testing" by G. Camilli, *Trans. A.I.E.E.*, Oct., 1926, and GENERAL ELECTRIC REVIEW, July, 1926.

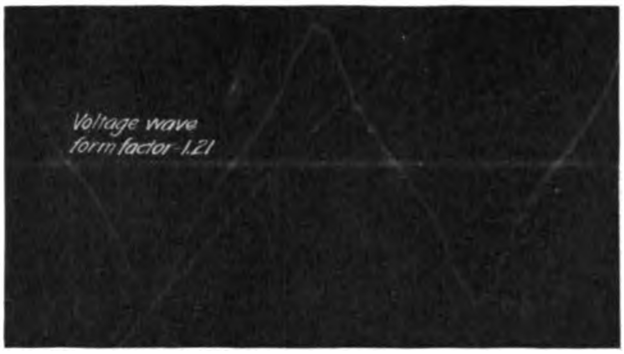

Fig. B. An Oscillogram of a Distorted Voltage Wave Such as May be Encountered in Core-loss Testing

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(3) When making core-loss measurements by the method of setting the voltage by the flux-voltmeter, the maximum flux density and therefore the *maximum value* of the exciting current is that corresponding to the sine-wave voltage, regardless of the wave shape of the test voltage. The effective value of the exciting current, however, will be variable with the wave shape of the test voltage.

To reduce the exciting-current component of the no-load measurement to the sine-wave basis, it will be necessary to have some applicable measure of wave distortion.

Form-factor, which is the ratio of the r.m.s. voltage to the average voltage, is one kind of measure of wave-shape distortion and is obtained in a simple manner by the flux voltmeter. Thus, if measurements are made at two wave shapes as widely different as possible, setting the voltages in each case by the flux voltmeter, the current corresponding to the sine-wave voltage can be obtained by extrapolation from the observed values of current and form-factor. This method naturally can be employed only where there are facilities (as in the test room) to change the wave shape.

Another method utilizes, as before, the flux voltmeter for setting the voltage but uses also a crest ammeter for measuring the *instantaneous maximum values of the corresponding currents.* Measurements should be made at 100, 86.6, and 50 per cent

[*Cont'd on next page*]

Connections

On distribution transformers having series-multiple windings, the series connection should be used during the test. If the transformer has taps on the excitation side, care should be taken to include the full winding.

In connecting the instruments, the voltmeter should be connected nearest the load, the ammeter nearest the supply, and the wattmeter between the two with its potential coil on the load side of the current coil, as shown in Figs. 13 and 14.

The watts and volts should be read simultaneously. Theoretically, the amperes should be read with the potential circuit of the voltmeter and wattmeter open, but ordinarily the difference is not appreciable. The load should then be disconnected and the "tare," *i.e.*, the I^2R losses of the two pressure coils, read on the wattmeter. These losses should be subtracted from the previous wattmeter readings in order to obtain the true no-load loss of the transformer.

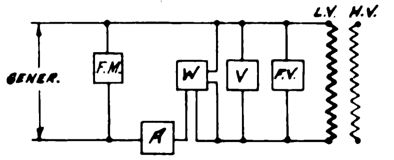

Fig. 13. Core-loss and Exciting-current Testing Connections for Single-phase Transformers. Instruments connected directly in the main circuits

Use of Current and Potential Transformers

In case the current and voltage of the circuit are beyond the direct range of the instruments, current and potential transformers may be employed as shown in Fig. 14. Instead of potential transformers, multipliers may be used in series with the potential coil of the wattmeter. Power transformers are not suitable for making measurements because they introduce an erroneous tare as potential transformers and large ratio and phase-angle errors as current transformers.

Core Loss of Three-phase Transformers

In measuring the core loss of three-phase transformers, it is advisable to take three entirely separate sets of readings by the two-wattmeter method, using each of the three lines in succession as the common. The average value of the three sets of readings should be recorded as the true no-load loss. In using the two-wattmeter method, great care should be exercised in reading the wattmeters because the load power-factor is usually very low (always less than 50 per cent) and therefore the two readings one of which is to be subtracted from the other may be nearly equal. This fact may lead to large errors in the net results (the difference between the two readings). Greater accuracy may sometimes be obtained by making the measurements from each line to the three-phase neutral and adding them together. This neutral may be either actual or artificial, as in Figs. 15 and 16.

Use of Low-power-factor Wattmeters

Losses in transformers should be measured preferably by low-power-factor wattmeters. The desirability of employing this type of instrument arises from the fact that power-factors of the order of 5 per cent are not unusual in core-loss tests, and power-factors as low as 2 per cent may be met in load-loss measurements. Under these conditions ordinary wattmeters would give very small deflections.

Frequency Measurements

The frequency has such a great influence on the losses at low power-factors that correct measurement of frequency is essential. Good frequency-meters are available in the market. In the absence of one, a good tachometer recently calibrated may be used on the testing generator.

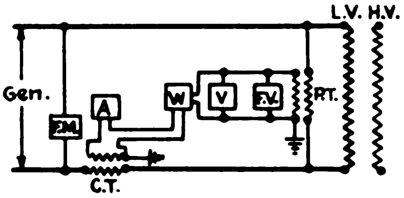

Fig. 14. Connections Similar to Those Shown in Fig. 13, Except for the Inclusion of Instrument Transformers

V: Voltmeter
A: Ammeter
W: Wattmeter
P.T.: Potential transformer
C.T.: Current transformer
F.V.: Flux voltmeter
F.M.: Frequency meter

Core Loss Correction for Temperature

Any increase in the core temperature reduces the eddy-current loss: this loss is a true I^2R loss in the core-sheets and is subject to the same laws as govern I^2R losses in conductors. Since the flux in the core and therefore the induced voltage are constant, the eddy-current loss decreases with increasing resistance due to increasing temperature.

The temperature coefficient of the resistivity of silicon steel is about 0.001. In other words, the eddy-current loss may be reduced one-tenth of one per cent

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[Footnote (3) Cont'd from preceding page]

voltages. These data determine the fundamental, third, and fifth harmonics of the exciting current, these harmonics being the only important components in determining the effective value of the exciting current.

Example:

Let A be the value of $I_{max.}$ corresponding to 100 per cent voltage.

Let B be the value of $I_{max.}$ corresponding to 50 per cent voltage.

Let C be the value of $I_{max.}$ corresponding to 86.6 per cent voltage.

Then:

$$\text{3rd harmonic} = \frac{A-2B}{3} = I_3$$

$$\text{5th harmonic} = A - \frac{(I_3+1.15C)}{2} = I_5$$

$$\text{Fundamental} = A - (I_3+I_5) = I_1$$

From which

$$I\ (\text{effective for sine-wave}) = \sqrt{\frac{I_1^2 + I_3^2 + I_5^2}{2}}$$

For further information on these methods, see "Reduction of Transformer Exciting Current to Sine-wave Basis," by G. Camilli, *Jour. A.I.E.E.*, Sept., 1927.

for every degree increase of temperature. But the eddy-current loss constitutes only about one-fifth to one-third of the total core loss so that the correction on the total loss will be about one per cent for every 30 to 50 deg. rise in temperature.

Theoretically, the reduction in eddy currents will lower the exciting current also, but the percentage reduction in the exciting current will be far less than that in the watt loss because this loss has only two components, *viz.*, hysteresis and eddy-current components, while the exciting current has three components, *viz.*, the magnetizing current, the hysteresis component, and the eddy current—the magnetizing current predominating. The eddy-current component is about one-fifth of the hysteresis component and the hysteresis current is between one-fifth and one-tenth of the magnetizing current. Furthermore, the hysteresis and the eddy-current components are in quadrature with the magnetizing current. As a consequence, 10 per cent or even 15 per cent change in the eddy-current component will not be noticeable in the total exciting current. For this reason no temperature correction need be applied to the exciting current.

COPPER OR LOAD LOSS AND IMPEDANCE VOLTAGE

The load loss of a transformer is the loss occasioned by the current drawn from the transformer while under load and includes a number of items as follows:

(1). The I^2R loss.

(2). The eddy-current losses in the conductors caused by the leakage flux in the conductors.

(3). The hysteresis and eddy-current losses in the tank, clamps, and core of the transformer, caused by the leakage flux cutting them. These losses are usually grouped under the term "stray losses."

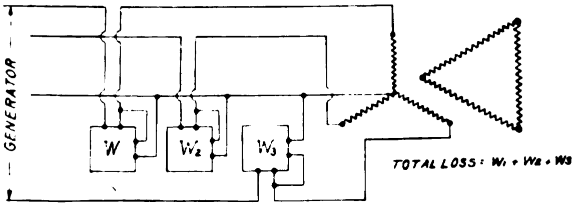


Fig. 15. Three-wattmeter Method of Connections for Determining the Core-loss of a Three-phase Transformer Having an Actual Neutral Available

The impedance voltage drop of a transformer should also be carefully measured for the following reasons:

(1). Transformers operating in parallel divide the load inversely as their impedance voltages, *i.e.*, the one having the higher impedance will take the smaller share of the load and vice versa. When transformers of different types are operating in parallel, the impedance of one transformer must sometimes be increased by introducing a reactor into the circuit. Therefore it is necessary to know the amount of the impedance voltage.

(2). The efficiency of a transformer is based on tested impedance watts, not on the calculated I^2R loss, and therefore it is essential that the impedance watts be measured.

The impedance ohms of a transformer may be considered as constant at all loads. The value is generally determined at full-load current, and the impressed voltage is then known as the "impedance volts," or when expressed in per cent of the normal rated voltage of the transformer it is termed the "per cent impedance drop."

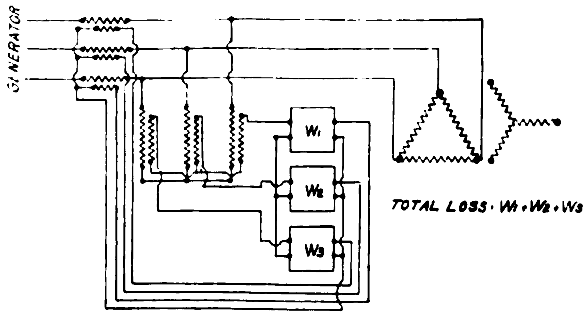


Fig. 16. Connections Similar to Those in Fig. 15, Except for the Introduction of Instrument Transformers to Create an Artificial Neutral Where an Actual Neutral is Lacking

Test

The copper or load-loss and impedance-voltage tests are made simultaneously. The total copper or impedance loss of a transformer is determined by short circuiting either the primary or the secondary winding, and exciting the other winding at such a voltage as will cause a circulation of full-load current in the transformer. The voltage that is necessary to circulate this current is the impedance voltage of the transformer.

The current should preferably be measured in the excited winding; this applies also to the current for the wattmeter. However, no appreciable difference will be found between the percentage values of the two currents in the excited and short-circuited windings because the voltage across the excited winding is very small and the exciting current varies faster than the square of the voltage. With transformers having as high as 10 per cent magnetizing current at normal voltage, 10 per cent impedance volts would call for an exciting current much less than one per cent, which would therefore be negligible.

Although measuring the current in the exciting winding introduces a slight theoretical error due to the exciting current, measuring the current in the short-circuited winding would also involve a small error by introducing into the short circuit the impedance of the current transformer and meters. For this reason it is common practice to make the short-circuit complete and to observe the current in the excited winding.

The test is applied in the following manner:

(1). Determine the approximate impedance voltage and current of the winding to be excited.

(2). Short-circuit the other winding of the transformer.

(3). Connect the instruments as shown in Fig. 17. Connect the transformer leads to the source of power through a circuit breaker.

(4). Adjust the voltage to give full-load current in the transformer, then make simultaneous readings of the voltmeter, ammeter, wattmeter, and frequency meter. Take several successive readings of the instruments to minimize errors.

The frequency should be checked by the frequency meter. In addition to the full-load current readings of volts, amperes, and watts, readings should be made of the temperature and the tare, and if used the instrument transformer ratios should be recorded.

The tare reading is a measurement of the losses in the meters and instrument transformers themselves. This reading should therefore be taken with the same circuit connections as those employed for making the power readings, with the exception that the main lines are disconnected from the transformer under test when taking the tare reading. Also, the voltage and frequency should be the same as held when taking the power readings. An effort should be made to read to tenths of a scale division.

Load-loss Temperature Correction

The load-loss as obtained by test may be corrected to the specified temperature (75 deg. C.) by dividing it into its I^2R and stray-loss components, as the ohmic loss increases with the temperature while the stray loss decreases with increasing temperature.

The correction for the I^2R loss is then:

$$\frac{I^2R \text{ loss at temperature } T}{I^2R \text{ loss at temperature } T_0} = \frac{234.5+T}{234.5+T_0} \qquad (1)$$

And the correction for the stray loss is:

$$\frac{\text{Stray loss at temperature } T}{\text{Stray loss at temperature } T_0} = \frac{234.5+T_0}{234.5+T} \qquad (2)$$

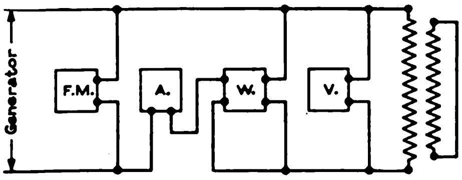


Fig. 17. Copper-loss (Load or Impedance-loss) and Impedance-voltage Testing Connections for a Single-phase Transformer. Instruments connected directly in the main circuits

where

T = temperature to which the losses are to be corrected

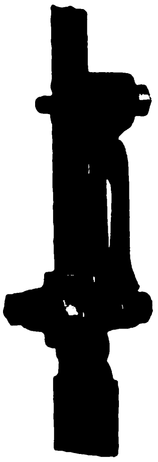
and

T = temperature at which the losses are measured.

Equation (2) is correct if all the stray losses are in the conductors but not if a considerable proportion of these losses is in the iron, because the temperature coefficient of resistivity of iron is not the same as that of copper Under the latter circumstances, the temperature correction for the stray losses will be greater than that given by Equation (2).

(To be continued)

Guide Clamp to Stop Breakage of Conductors



A common cause of trouble in outdoor station installations is the fact that the conductors break as the result of crystallization close to the point where they are rigidly held to the connection members of oil circuit breakers, transformers, and disconnecting switches. This danger has been eliminated by a guide clamp which consists of a cast arm four to six inches long, provided with holes at each extremity for bolting to the conductor and terminal. Its function is to distribute the occurrence of the point of flexure over an appreciable length of conductor and thus to relieve the metal adjacent to the connecting stud of the full effect of vibration and swinging.

The clamp is made in a variety of sizes suitable for attachment to conductors ranging from No. 2 (A W G.) up to 2½-in. iron-pipe-size copper tubing, and can be applied to the terminals of standard outdoor station apparatus, as well as to tubular conductor connector fittings in outdoor bus work. It is made of copper alloy and is provided with hot-dipped galvanized hardware. For application to existing installations, extra long holding bolts are used.

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Electric Wiring; Theory and Practice. Ed. 3. W. S. Ibbetson. 424 pp., 1929, Lond., E. & F. N. Spon.

Electrification of Steam Railroads. Kent T. Healy. 395 pp., 1929, N. Y., McGraw-Hill Book Co., Inc.

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(An introductory volume to the author's more comprehensive text "Principles of Radio Communication." Nevertheless it is not a collection of excerpts from the larger volume, for it "has been written entirely anew." Practically no mathematical knowledge more advanced than algebra is necessary for the comprehension of the text. The seven chapters treat: "Simple Laws of the Electric Circuit," "Special Laws for Radio Circuits," "General Idea of Radio Communication," "The Vacuum Tube and Its Uses," "Radio Telegraphy," "Radio Telephony," "Receiving Sets." There is provided a set of problems applying to each chapter. The volume should appeal to those wishing something more sound and thorough than many of the existing popular texts, but who have neither the preparation nor the desire to attempt the more advanced works on radio.)

Engineering Electricity. Ed. 2. Ralph G. Hudson. 214 pp., 1928, N. Y., John Wiley & Sons.

Industrial Traffic Management. Leslie A. Bryan. 392 pp., 1929, Chgo., A. W. Shaw Co.

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Mechanics for Engineers. Leroy W. Clark. 192 pp., 1928, Balt., Williams and Wilkins.

Pitman's Technical Dictionary of Engineering and Industrial Science in Seven Languages—English, French, Spanish, Italian, Portuguese, Russian, and German. Ernest Slater (Comp.) Vol. 1, 581 pp., 1928, N. Y., IsaacPitman & Sons.

(This is the first volume of a four-volume set constituting a ployglot technical dictionary of outstanding merit. The work is arranged on an English alphabetical base, and includes a wealth of words and phrases found in the literature of science, engineering, and the industrial arts. The arrangement is in parallel columns, each column being devoted to a separate language. The fact that English is the sole alphabetical key-language limits the usefulness of the dictionary unless some form of index scheme should appear in a later volume to indicate the exact locations of the foreign-language terms. The compiler and his collaborators would seem to have a thorough grasp of the intricacies and pitfalls of translation work. For instance, some sixty pages at the beginning of this first volume are devoted to several explanatory chapters which should be of considerable aid to the translator. One of these is on "The Art of Technical Translation;" another on "Alternatives, Refractory Idioms and Peculiar Phrases;" another on "Mechanical Motion, Relation, Position, Cause and Effect" as expressed by idiomatic use of prepositions and common phrases. A useful list of common engineering abbreviations is also included.)

Proceedings, International Congress on Illumination, 1928. 1443 pp., 1929, N. Y., International Congress on Illumination.

(This substantial volume includes, also, the Proceedings of the Seventh Plenary Session of the International Commission on Illumination, and Selected Papers from the Twenty-Second Annual Convention of the Illuminating Engineering Society. The numerous papers and reports included are in the language of presentation; however, all of them are provided with brief summaries in English, French, and German. Committee reports and cognate papers are presented in groups covering the following broad headings: street lighting, glare, automobile headlights, flux distribution, photometry in its various phases, daylight, illumination, factory lighting, school lighting, definitions and symbols, colored signal light glasses, diffusing media, motion picture lighting, and colorimetry. In addition there are separate papers on lighting education, aviation lighting, residence illumination, and show window lighting.)

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Telephone and Power Transmission. R. Bradfield and W. J. John. 238 pp., 1929, N. Y., John Wiley & Sons.

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("Designed as a text in illumination for undergraduate students" and intended to be accompanied by lecture demonstrations and laboratory work. The chief subjects covered are the various illuminants, photometry, illumination measurements, luminaires, brightness and glare, light projection, the eye and its relation to illumination, daylight, street lighting, recreational lighting, industrial and commercial lighting, and the illumination of residences and public buildings. Many of the chapters are provided with problems and references to collateral reading, and the final chapter is designated as a "Laboratory Manual," presenting 24 experiments applying to illumination work.)

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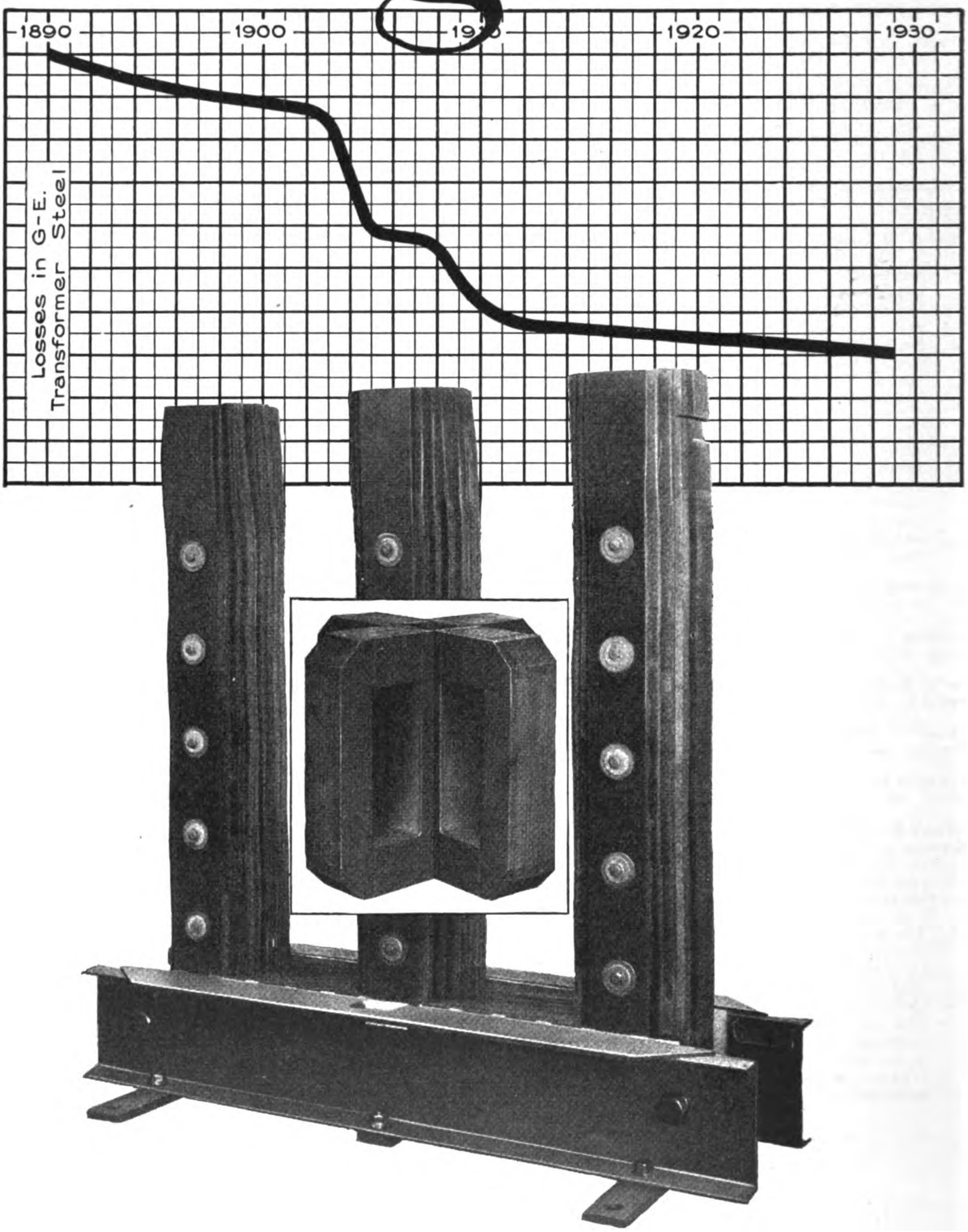
Progress



GENERAL

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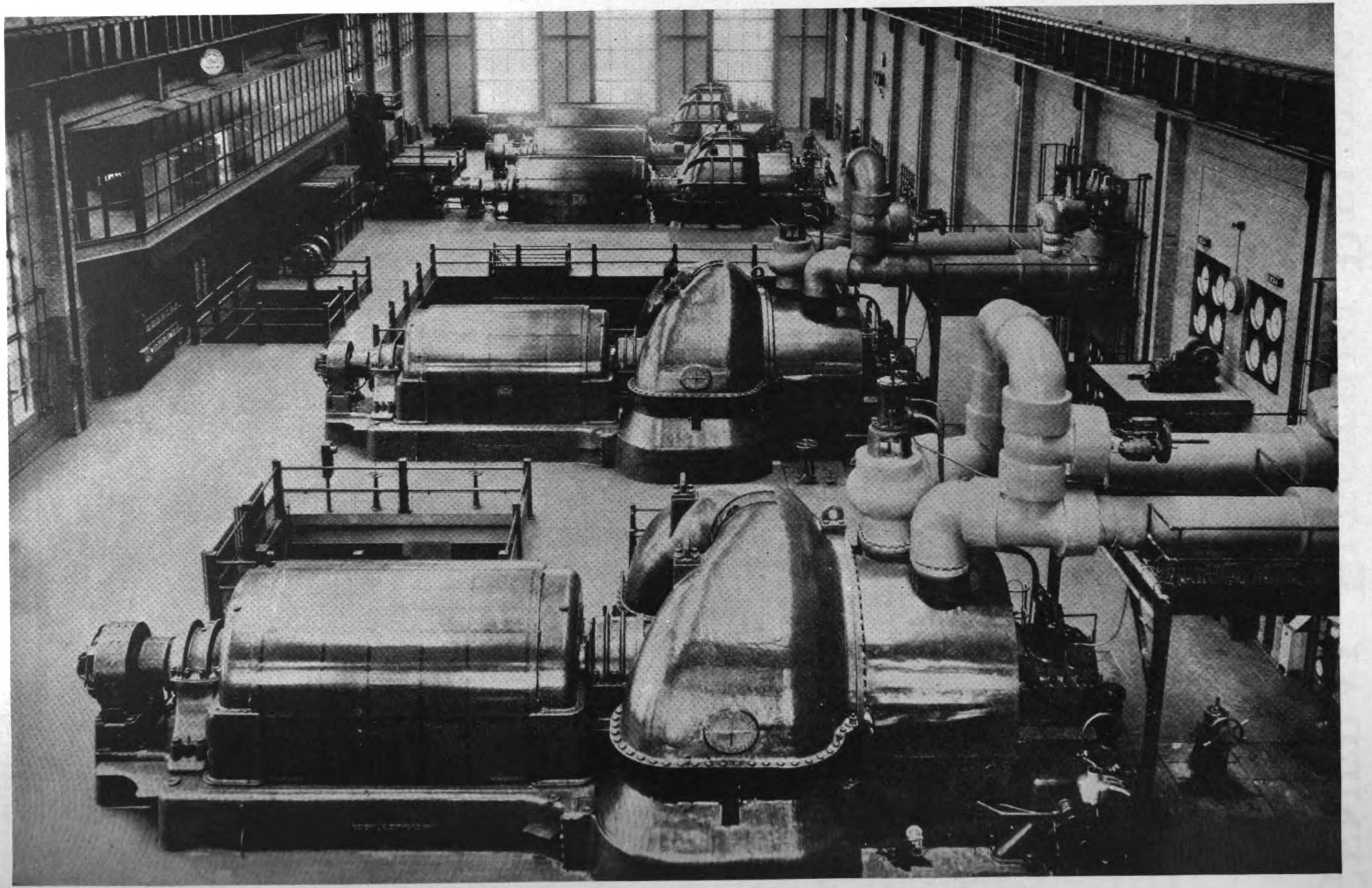

INTERIOR OF OHIO POWER COMPANY'S STATION AT PHILO, OHIO

The machines installed are: one 165,000-kw. triple-compound and two 40,000-kw. single-casing turbine-generator sets. All are designed for 600 lb. steam pressure with reheat

GENERAL ELECTRIC
REVIEW

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POWER

In turning the pages of a small dictionary on our desk we were struck by the rather pleasing fact that but one word separated Poverty from Power. Poverty was separated from Power by the single word Powder. After noting this fact we found ourselves almost unconsciously humming a verse from Kipling's "Secret of the Machine":

> "Do you wish to make the mountains bare their head
> And lay their new-cut forests at your feet?
> Do you want to turn a river in its bed,
> And plant a barren wilderness with wheat?
> Shall we pipe aloft and bring you water down
> From the never-failing cisterns of the snows,
> To work the mills and tramways in your town,
> And irrigate your orchards as it flows?
>
> "It is easy! Give us dynamite and drills!
> Watch the iron shouldered rocks lie down and quake
> As the thirsty desert-level floods and fills,
> And the valley we have dammed becomes a lake!"

The story of our modern world is, indeed, in a great measure the story of how man has used powder, dynamite, and his own indefatigable energy in eliminating poverty by damming rivers and blasting rocks, not only to plant barren wildernesses with wheat but, more particularly, that we might have power and have it ever more abundantly. The power that we are today generating in our steam and hydroelectric stations throughout the land is, as we see it, the antidote for poverty and has revolutionized our lives economically, socially, and industrially.

In the radical changes that have come about in our mode of doing things during the last fifty years, we believe that our newer and better methods depend more upon the increased use of power than on anything else.

If we confine our remarks to America we can say with certainty that the ever increasing use of power and the multiplication of its applications in the home, in the office, and in the majority of industries has been the greatest and most potent factor in building up the national wealth.

Great as the changes of the last half-century have been, we believe that our public utilities are going to do more for us in the next ten or fifteen years than they have accomplished in the last fifty years.

Just as the mighty oak springs from the tiny acorn, so have the gigantic American public utility industries sprung from small beginnings. Thomas A. Edison's small 1200-horsepower station at Pearl Street in New York City will always be regarded as of historic interest, and may justly be looked upon as one of the nuclei from which sprang this tremendous growth.

How rapid and great this growth has been can, in a measure, be shown by the statement that in 1927, well under half a century after Edison's Pioneer station, central station service was available to every city in the United States with a population of 5000 or more; to 97 per cent of all communities between 1000 and 5000; to 50 per cent of all communities between 250 and 1000 people and to 25 per cent of all townships of less than 250 inhabitants.

There are now some 4400 electric utility enterprises in the United States alone, serving considerably over twenty-one million customers. It is interesting to note that in the year 1927 of the 75,116,000,000 kilowatt-hours generated, about two-thirds was produced by fuel burning plants and one-third by water power.

In the year 1928 considerably more than ten billion dollars was invested in the American utility industry and during that same year the gross revenue had reached nearly two billion dollars.

These figures are tremendous, but the rapidity of this growth is best told by stating that in the last twenty years the equipment for generating power in American central stations has grown from five million horsepower to thirty-six million horsepower.

Of this great total, nineteen million horsepower was sold to manufacturing industries. There are some people who can read sermons in stones. There ought to be many more who can read the economic history of a nation in these figures. Every industrial worker in America has over 4½ horsepower at his disposal, and thus, the American workman has become to a far greater extent the director of mechanical energy than the exerter of muscle power. It is this simple fact that has given to the American factory that increase in both quality and quantity of production that has astonished and perplexed the world.

We regard the American public utility industry as the very life blood of the country, energizing and vitalizing every section where its thin red streaks of civilization are spread. The electric transmission lines are to a country just what the blood vessels and nerves are to the human body. They energize, they vitalize, they give life where no life could be without them.

The mighty expansion of the public utility business today assures the prosperity of the future in a degree that, if it had been told to our fathers, would have outshone their brightest visions of Utopia.

The early history of American public utilities was of a turbulent nature. It was permeated with useless and wasteful competition and harassed by uncertainties. There was no government control in the early days. We doubt if history anywhere holds a better example of success and prosperity as the first fruits of coöperation between producer and consumer than is shown in the case of public utility growth.

Order displaced chaos as each state of the Union, one after the other, recognized electric service as essential to the prosperity and growth of the commonwealth and decreed that wasteful and destructive competition should give way to a form of state-regulated monoply. So quickly and so thoroughly was recognized the wisdom of protecting the consumer, without undue hindrance to pioneer developments, that today we find public service commissions established in every state in the Union with the single exception of Delaware.

This economic theory that has been developed in America to govern the regulation of public utilities embraces in its present scope electricity, water supply, gas, street railway, bus, express, telegraph and telephone companies. In general, the theory is this: that in exchange for the exclusive right to serve a particular territory and to make use of such public property as streets and roads, etc., the state assumes the right to supervise and regulate the rates charged as well as to dictate the standard of service to be rendered.

The results achieved under this far-seeing policy are well described in the following paragraph taken from the new (14th edition) *Encylopedia Britannica:*

"It is under this general form of state regulation of private enterprise that the electric utility industry of the United States has made its extraordinary record of growth during the present century, to a point where the country uses nearly as much electricity as all the rest of the world."

How well engineering developments, research, and able management have served the country is admirably shown by quoting a paragraph from a recent United States Geological Survey Report.

"In 1927 the operators of the public utilities power plants performed the remarkable feat of generating 2½ billion more kilowatt-hours of electricity with the use of 150,000 tons less of fuel than in the previous year."

We can add to this statement the fact that in the year 1928 the average domestic rate for electric energy for the entire country was 15 per cent less than for the year 1913, and that electric energy was the only item in the government cost-of-living list to show a decrease when compared with pre-war averages.

We have quoted some figures from an article by E. W. Rice, Jr., appearing in this issue and some from other sources to show the magnitude and the rapidity of growth of the American public utility business. We could have quoted many more statistics but figures after a time become wearisome.

The public utilities, like many other things American, have become giants. America in the past learned much from other countries and be it said to her credit that she has made the full use of what she learned. It sometimes seems to us that the world now has much to learn from America, and especially the all-important fact that big business is good business.

There are some, we know, who lament the fact that the public utility business is big and prosperous. There are some people who always seem to fear anything big. The great paradox about American business that the world at large should heed to-day is that all those agenices of American commercial life that were feared a quarter of a century ago because of their bigness have developed, through the guidance of wise regulation, to be those factors that have built up the national wealth and at the same time raised the standard of living for the workingman and led to the most equitable distribution of wealth to be found in any country of the world.

Dollars are not filthy things as some have imagined. They are in reality only the tokens of work done in the past and opportunities intelligently taken. The man in the street, the consumer and the workingman in the shop have the same privileges as that mythical figure, "The Magnate," to share in the prosperity of big business.

It is the large coprorations and our stock exchanges that have given the tinker and tailor, the soldier and sailor an opportunity to share in the national wealth. In the future, the man who is nothing but a critic and the person who does nothing but grumble will be poor; but the person who has sufficient energy and intelligence to work and to save and to invest his savings wisely in America's great business institutions will not be poor.

There is only one word between Poverty and Power—that is Powder. We take the privilege of coining a new synonym for powder—Energetic Intelligence. J. R. H.

Recent Economic Developments of Electric Power

Internal Combustion Engine—Electricity in Manufacture and Daily Life—Fuel—Water Power—Financial Status—Steam and Mercury Units—Transmission—Switchgear—Saturation of Demand

By E. W. RICE, JR.
Honorary Chairman of the Board, General Electric Company

(A paper delivered at the World Power Conference in Tokyo, Japan, October 29–November 7, 1929)

THIS discussion of economic developments of power since the last World Power Conference will be limited to conditions in the United States. The development of mechanical as well as electrical power will be briefly sketched, and afterwards our discussion will be confined to the electric power field.

The improvement in the economic condition of our country during the past decade has been the subject of much discussion, with the general agreement that an intimate relationship exists between its favorable progress and the increasing use of power.

While other forces have influenced our economic status, it is believed that the most significant contribution will be found in the fact that during the past two decades the use of power has increased about twelve times faster than our population.

The vast number of motor cars and trucks used for transportation and the almost universal use of electricity in industry and in the home constitute the most striking phenomena of our time.

The Internal Combustion Engine

As is well known, the motor car owes its existence to the light-weight, efficient, self-contained power plant made possible by the internal combustion engine. It is doubtful if the amazing growth of electric power would have been possible without the development of another great source of power, the steam turbine.

In the year 1899 the mechanical power applied to vehicles was negligible, but during the succeeding decade development was rapid, and by 1909 passenger automobiles and trucks used 8 million hp., a remarkable growth for a young industry. However this was but the beginning; acceleration so increased that in 1927 the 750 million hp. mark was passed. At the present time a billion (1,000,000,000) hp. is devoted to such transportation. Thus has this new agency of power increased over one hundred fold in twenty years, and dwarfed all other applications.

It seems incredible, but it is a fact that the power installed on our motor cars and trucks is three times the grand total of power used for all other purposes. In fact, more power is applied to moving material in motor trucks over our highways than is required by our railroad system, and more power is devoted to moving passengers in buses over our highways and streets than is used by our railroads for passenger traffic.

No description of the development of power and its influence on modern life would be complete that failed to take account of the contributions to transportation on land, sea and air of the internal combustion engine power plant. But we must leave this interesting field to others better qualified and proceed to the study of the economic changes produced by the introduction and wide application of electric power.

Perhaps the most important agency in our electrical development is the central electric power station, to which we will largely devote our attention.

Twenty years ago, in 1909, the power installed in central stations was a little over five million hp. By 1927 it had increased over seven times and reached 36 million hp. Of the 36 million hp., the equivalent of about 19 million hp. was sold to the manufacturing industries. The balance of 17 million hp. was sold for general lighting and power purposes in the twenty million homes of our country and for miscellaneous lighting and power in cities, towns and hamlets.

Electricity in Manufacture

Referring to the power used in manufacturing, we find that the amount of primary power installed has not changed materially during the past twenty years. This lack of increase coincides with the rapid growth of electric power as a substitute for primary mechanical power, and such electric power was largely supplied by the electric central stations.

The central stations sold to manufacturers about 200,000 hp. in 1899; this had grown to 16 million hp. in 1925. Thus the total power used in manufacturing has steadily grown, but the significant change has been in the use of electric power purchased from central stations.

Manufacturers recognizing the economic value of electric power not only purchased power, but installed electric motors driven by electricity generated in their own plants, and it is a tribute to the economic value of the electric drive in manufacturing to find that while in 1909 but five per cent was electric, its use rapidly expanded until in 1925 three-quarters of the power used in manufacturing operations was electrical. It is significant that two-thirds of this striking trend towards the greater use of purchased electric power is undoubtedly due to the recognition of the relatively greater economy and reliability of the central station service as contrasted with that of the isolated plant.

It would appear that in no field of human activity has the value of electric power better been recognized than in that of manufacturing. It has found many applications, such as heating, welding, lighting, electric furnaces, annealing, japanning, electro-plating, etc.

The United States census shows that the industrial output on the quantity basis and with price variations eliminated, increased by 70 per cent during the period from 1914 to 1925. During this same period the quantity of power increased by 61 per cent, and practically the entire increase was electric.

Each industrial worker now has an average of 4½ hp. at his disposal. This power, which is largely electrical, is reliable, convenient, flexible and easily controlled, and increases man's capacity for production many fold. It is therefore claimed that our workman is now the most productive industrial unit in the world.

The net result is not only an increased quantity of goods produced, but also a product of superior quality. The increased unit output of machinery and man also makes possible a reduction in the unit cost of goods, not only without decrease in wages, but with a substantial increase of wages. These results are of the greatest economic and social value.

Electricity in Daily Life

During the past five years there has been a steady increase in the supply of electricity made available in an increasing number of communities. It is stated that not only has every urban district the advantages of electricity, but every city of 5000, fifty per cent of all communities between 250 and 1000, and more than 25 per cent of those of less than 250 population have this service. This steady increase in the distribution of electric energy has been due to the technical progress in the art of generation, and of interconnection of transmission lines and better methods of distribution, as well as to the increase in the financial strength of the public utility companies. Meanwhile there has been a marked tendency towards consolidation of small electric stations into larger operating units, and at the same time the number of communities served has been considerably enlarged.

This has been accompanied by a phenomenal increase of customers of central station electric light and power.

The continued growth of the electrical industry has created a demand for larger units of production and distribution and the electrical interconnection of systems. These have all tended to an improvement of load factor, reduction of cost and improvement in service.

Saving in Fuel

Our fuel supplies have also been conserved by the continued decrease in the relative amount of fuel required by the steam plants of our central electric stations. This has resulted from the increased efficiency of the steam turbo-generators and improvements in boilers and the general methods of producing steam. For example, in 1919 an average of 3.2 lb. of coal (or its equivalent) was used for each kw-hr. generated. In 1924, five years later, this had been reduced to 2.21 lb., and by 1928 it is reported that only 1.76 lb. were required.

Although the kw-hr. generated from fuel by utility plants had grown from 25 billion in 1919 to 50 billion in 1928, doubling in the decade, the fuel used increased but 14 per cent, from 35 million tons to 42 million tons.

The United States Geological Survey states in a recent report: "In 1927 the operators of the public utility power plants performed the remarkable feat of generating 2½ billion more kilowatt-hours of electricity with the use of 150,000 tons less of fuel than in the previous year." It is estimated that "if the central station industry in 1927 had not increased its efficiency over 1919, there would have been burned 40 million tons of coal or its equivalent more than was actually used." This may be considered as representing an economic value of 150 million dollars ($150,000,000) per year.

Use of Water Power: Hydroelectric

Central electric stations use two sources of energy: fuel, as coal, gas and oil, and the power of falling water, the so-called "white coal." About 60 per cent of the aggregate power is generated from fuel and 40 per cent from water. This relative proportion has remained practically unchanged during the past five years. In 1922, of a total of 48 billion kw-hr. generated, about 17 billion were due to water power, while in 1927 the corresponding figures were 80 billion kw-hr. and 30 billion kw-hr., respectively.

Wide fluctuation in precipitation, and consequent flow of water, control the amount of available electric power, making it nearly always necessary to provide stand-by fuel burning plants in connection with hydroelectric developments. Nevertheless the conservation of the nation's supply of fuel effected by the use of water power is notable, being equal at the present time to 30 million tons of coal per annum.

Investment, Income, and Customers of Central Electric Stations

About 4½ billion dollars ($4,817,000,000) were invested in the electric central stations of the United States in 1922. This had grown in 1928 to over ten billion dollars ($10,300,000,000). The corresponding gross revenues were over one billion dollars ($1,072,000,000) and nearly two billion dollars ($1,908,000,000).

The output in kw-hr. meanwhile increased from approximately 40 billion to over 80 billion, and the number of customers, which was only two million two decades ago in 1909, had grown to 23,400,000 in 1928, of which latter about 20 million were residential customers. It is interesting to note that the number of residential customers has practically doubled during the past ten years.

In 1922, according to the *Electrical World*, 40 per cent of the nation's homes were electrified. In 1928 this had grown to 67 per cent. In other words, about 44 million people in 1922 were living in homes lighted by electricity, while in 1927 some 74 million enjoyed the advantages of central station light and power.

According to the National Electric Light Association, the central station budget for 1929 is $790,000,000, of this $225,000,000 are for generating plants; $502,000,000 for transmission, distribution and substations; and $60,000,000 for miscellaneous items. The amount to be expended for generating plants is divided: $161,000,000 for steam, and $64,000,000 for hydroelectric.

It is a truism that the development of power is founded upon science and engineering. This fact does not detract from the value of other human contributions. Fortunately, at no time in the world's history has the engineer and scientist received greater recognition. The scientific viewpoint and method of solving Nature's secrets have proved so successful that they are being extensively copied in other human activities. Research is now the slogan of industry, finance, economics and politics.

It is therefore desirable to ascertain what the engineer and scientist have been doing during the past five years or more to advance the use of power.

No attempt will be made to describe these accomplishments in fields other than electric, and details will be generally omitted, as all these matters have been covered by other writers in careful and authoritative papers contributed to this Conference. An effort will be made to sketch some of the significant developments.

Steam Turbine Electric Units

In steam turbine-electric generators the significant features are: the rapid growth of the aggregate power installed, the increase in steam temperatures, the use of higher steam pressures, the continued enlargement in size of individual units; and a decrease in unit cost and continued advance in the efficiency of conversion of fuel into electrical energy.

The installed power of steam turbine electric units grew from an aggregate of 14,000,000 hp. (10,400,000 kw.) in 1922 to over 27,000,000 hp. (20,140,000 kw.) in 1928.

Five years ago the larger individual units ranged from 30,000 kw. to 50,000 kw. At the present time 50,000 kw. to 75,000 kw. are common and installations of 160,000 kw. and 208,000 kw. machines are being made. Even larger units are under consideration for the future.

The extensive use of large turbine units in the United States may be illustrated by the experience of one manufacturer, who has supplied central stations with 154 machines of 30,000 kw. or larger, aggregating more than 5,500,000 kw., and in addition furnished some 38 machines rated from 50,000 kw. to 75,000 kw., aggregating over 2,250,000 kw.

Steam temperatures have increased to 725 degrees F. (385 degrees C.) at the throttle, with 750 degrees F. (398.8 degrees C.) produced by reheat between the high- and low-pressure stages.

The steam pressure of 275 lb. of a decade ago rapidly increased to 700 lb., now in common use on the larger units. Super-high-pressure units of 1200 lb. started about five years ago, with a few machines reaching 10,000 kw. capacity, whereas now a number of 50,000-kw. units are under construction by one manufacturer, and the aggregate capacity under construction or in operation has reached a total of 400,000 kw.

There has been a steady reduction in the heat consumption of turbines brought about by improvement both in the efficiency of the turbine itself and through an increase in the steam cycle efficiency. The first resulted from better design, higher speed and larger capacity; the second, from increase in steam pressure and temperature, and the increased use of resuperheat and steam extraction for water heating.

The large modern units give steam performances which are noticeably better than the average results already mentioned, as obtained in practice by the electrical central station industry.

The figures given for efficiency of the electric central station are commonly stated in pounds of coal per kw-hr. This is the only figure under the control of the turbine designer.

However, the heat consumption of the power station is the more significant economic factor, but as this involves many factors which are beyond the control of the turbine designer, this information must be obtained from actual operation or be based upon specified fuel, boiler efficiency and other pertinent operating conditions.

On the basis of 13,500 B.t.u. per pound of fuel, boiler efficiency 85 per cent, and reasonable assumption as to auxiliary power, modern turbine generator units of large size produce a kw-hr. for 0.9 lb. or less of fuel, corresponding to 12,150 B.t.u. Better results are naturally realized under test conditions. That such results are not realized by the industry on the average at the present time is due largely to the number of earlier and less efficient steam units still in service. Since the most modern plants now going into operation will produce a kw-hr. on about 0.9 lb. of coal, as stated, it can be seen that even though no new developments are brought about in the future, a continued reduction in the fuel cost of power will result as a greater percentage of the power is produced in modern plants.

High land values in certain localities and mounting construction costs have led to the design of a steam turbine unit in which the high-pressure unit is superimposed on the low pressure. This reduces the foundation space and ground area to that required for the size of the low-pressure unit.

The remarkable advance in the art of design of steam turbine electric units is indicated by the fact that in the early type of steam turbine-generator units about 80 lb. of material were required per kw. of rated capacity. This figure has been reduced in recent construction to about 18 lb.

Emmet Mercury Vapor Process

A large unit of 10,000-kw. capacity operating under the mercury vapor process has been installed by the Hartford Electric Light Company, supplanting a smaller unit of 2000 kw. The 10,000 kw. unit was started in November, 1928, and operated successfully for several weeks, during which period it demonstrated its high thermal efficiency by producing the equivalent of a kw-hr. for 9140 B.t.u. Certain changes were then found desirable. These changes do not affect the prospects of ultimate success of this important attempt to increase the thermal efficiency. The results obtained to date have been given in a paper by the inventor.

A recent development of importance is the adoption of double windings for large steam generators. A unit of this character, rated at 160,000 kw. with a single electric generator, driven by a single turbine, is now undergoing test and will soon be installed at the East River station of the New York Edison Company. The double winding reduces by one-half the concentration of power in a single machine, and at the same time affords the economy and simplicity of a single large unit. Considerable savings in switchhouse costs are effected.

Hydrogen as Cooling Medium

The use of hydrogen as a cooling medium for electric generators, synchronous condensers, etc., has been considered for some time, and much important work has been done. On account of its universal presence and cheapness, air has been used almost entirely as a cooling medium for large rotating electrical machinery. Hydrogen gas, however, offers many economical and technical advantages which are just beginning to be realized in practice. The lower density of hydrogen reduces the windage loss over 90 per cent. Its better heat conductivity, which is 7¼ times higher than air, permits 30 per cent more heat to be removed by forced convection. The hydrogen atmosphere also prevents oxidation of electrical insulations which retain indefinitely the flexibility so necessary for durability. Damage due to corona discharges is reduced and concentrations of electrical stresses avoided.

The accumulated effect of the above advantageous features permits an increase of 30 per cent in output to be obtained at atmospheric pressure, and at 15 lb. gauge, an increase of 50 per cent. In addition to this are the collateral advantages which follow from the practical elimination of noise and the fact that a machine equipped for cooling by hydrogen is totally enclosed and waterproof, and thus may be placed outdoors with the usual saving in installation and building charges.

Machines of 10,000 kw. to 15,000 kw. are already in operation and orders for others have been placed with manufacturers. The economic value of the substitution of hydrogen gas for air as a cooling medium in such machinery is therefore definitely established and we may expect the practice to be extended.

Mercury Rectifier

The mercury rectifier is showing its economic value in electric railway service. Many units of from 500 to 1500 kw. rating at 600 to 1500 volts are in operation.

The mercury rectifier in efficiency, cost, weight and dimensions is economically superior to other forms of conversion apparatus in the higher voltage range of 1500 to 3000 volts d-c. used in electric railway service. and its use in this field is extending at a rapid rate.

Transmission Lines: Lightning Protection, Interconnection, Direct-current Transmission, Underground Cables

In transmission, the principal extension has been in the higher voltages, between 66,000 and 220,000 volts, which now aggregate about 50,000 circuit miles. The 220,000-volt lines have been more than doubled in the past few years.

The conditions surrounding the electric stability of long distance lines have been carefully studied and improved methods have been introduced.

Barriers to the extension of long distance transmission beyond the present practice seem to be more of an economical than technical nature.

A 5,000,000-volt lightning generator has been added to the equipment of a manufacturing research laboratory. This gives a higher voltage then has ever been measured on a transmission line as a result of a lightning stroke. It is therefore possible to submit transformers, insulators, and other electrical apparatus to electrical stresses greater than those which are likely to occur in practice. This laboratory work has been supplemented by extensive studies on transmission lines under actual operating conditions. As a result, the methods of protection from the destructive effects of lightning on power circuits have been greatly advanced.

The interconnection of large electric systems is progressing rapidly and the economic advantages are found to be greater reliability of service, better "use factors" of expensive electrical apparatus which tends to reduce the amount of such apparatus needed for a given service supply and so favorably to affect the cost per kw-hr. of energy sold.

One of the most important interconnections is that being arranged between three large systems in Pennsylvania. It is estimated that as a result, a saving in investment equivalent to $40,000,000 of power plant capacity will be realized.

The available power supply and its reliability are increased by interconnection and exchange through different watersheds. In some instances the diversity factor is improved by the fact that different parts of interconnecting systems operate in different time zones.

These advantages tend to offset the handicap due to the increase in cost per kw. of generating stations

It was popular at one time to forecast the installation of mammoth electric power plants near coal mines, and it was believed that cheap coal thus rendered available would favorably affect the cost of electrical energy. With the low freight rates obtaining in the United States at present, coal, generally speaking, may be transported "long distances" more cheaply than electric power can be transmitted similar distances. Besides, the enormous amount of water required for condensation purposes by the steam plants cannot usually be found in the vicinity of coal mines.

The vacuum tube rectifier may prove to be of great economic advantage in connection with the transmission of power. These tubes may be used to convert the high-tension alternating current into high-tension direct current, which can be transmitted to the receiving station where an inverted vacuum rectifier, known as the "thyratron" will change the direct current back into alternating current. Such high-voltage vacuum tubes give promise of not only being useful for transmission of large amounts of power to extremely long distances such as 500 to 1000 miles, but may have an important application in large cities. In many cases the vacuum tube rectifier and thyratron system may increase by two or three times the useful power capacity of existing underground cables. The investment in such cables runs now into many millions of dollars and any practical method of multiplying their output will prove of unusual economic importance.

In the development of high-tension underground electric cable, oil-filled cable is the outstanding achievement during the past five years.

Two oil-filled cables of 132,000 volts have been placed in service. Development of 220,000-volt cable is under way. These are single conductor cables intended for 3-phase. In addition, 75,000-volt, 3-conductor cable has been developed. Designs are being simplified and installation costs reduced.

Transformers

These have increased in size to meet the demand of the larger generating units. Probably the largest transformer ever installed was placed in the Huntley station of the Buffalo General Electric Company this year. It has a rated output of 110,000 hp. and occupies a space of 23 ft. by 14 ft. by 14 ft. and weighs, complete with oil, 165 tons.

As the transformer is the flexible connecting link between the generator and the supply circuit, its economic value has been increased by the use of variable ratio transformers adapted to handle large currents and high voltages, automatic in operation, and designed to permit change of ratio while operating under load.

Transformers, especially those on long transmission lines, are subjected to the shock of high-voltage impulse currents induced from lightning and switching which produce abnormal strains, irregularly distributed, with the result at times of electrical failures.

Important improvement has been effected by providing suitable electrostatic shields which insure a uniform distribution of the impulse voltage between the coils and turns of the windings. The resulting product, called a "non-resonating" transformer, is rugged and highly resistant to abnormal high voltage. This construction has been found practically to eliminate failures and at the same time has the added economic advantage of reduction in weight and size.

The transformer is probably the most efficient of all electrical devices. On account of its economic importance there is continued effort to increase these already high efficiencies. One manufacturer recently produced a 60-cycle transformer of 15,000-kv-a. capacity with an efficiency at three-quarter load of 99.53; a 20,000 kv-a. with an efficiency at full load of 99.52; and a 25-cycle, 83,333-kw. autotransformer with the extraordinary efficiency at three-quarter load of 99.62.

Electric Welding

A notable extension of electric arc welding has been made in its recent application to the construction and erection of large steel frame buildings, electric welding being substituted for riveting. Considerable reduction in cost is effected with the added social benefit of elimination of the deafening noise of the present riveting process. The same method is being applied to other large steel structures such as bridges and ships. Hundreds of miles of iron pipe for long distance oil and water lines are being electrically welded. Its use in machinery has revolutionized old designs, and to a considerable extent superseded large castings. The resulting product is better and of lower cost.

Ship Electrification

The electrification of ships has outgrown its early bounds of naval application, has entered the field of merchant shipping, and is now an important economic factor to be considered in all types of vessels.

The electric ship is characterized by its main power plant, which permits of the reversal and speed control of the propellers by the movement of a control handle, without the necessity for changing the direction of rotation of the prime mover. Reliability, economy, ease of operation, and rapidity of action are its principal attributes. The prime mover may be either a turbine or Diesel engine and both types have been used.

The general trend is towards complete electrification. Excellent examples of the electric-driven merchant ship may be found in the S. S. *California*, *Virginia*, and *Pennsylvania* of the I. M. M. Company.

Switchgear: Oil Switch, Distant Control, Isolated Phase, Rupturing Capacity, New Types, Vacuum Switch, Automatic Substations

The writer, about the year 1900, foresaw the outstanding value of the oil switch and devised a number of improvements. Briefly, these consisted in a design which materially reduced the quantity of oil required and placed each element of the 3-phase switch in a separate fireproof cell, coupled with a method of electric control from a distant point.

In a paper given before the American Institute of Electrical Engineers on August 22, 1901, this improved system was described as follows:

"The circuit breaker or switch differs radically from older forms in the separation of the phases as indicated and also in the separation of the contacts in each phase in two separate oil pots. This method of construction, together with the separation of phases in separate fireproof compartments accounts for the unusual effectiveness of the switch in practical operation.

"The switchboard should preferably be placed in a separate room so that any accident will not injure the switchboard operator or the switchboard mechanism. Each switch should be of ample capacity to interrupt the entire capacity of the generator at full voltage, and even take care of the concentration of the entire load of the station as in a short circuit. This switch should be placed in a cell of fireproof material and preferably electrically controlled from a central point. The bus bars should be carefully protected in fireproof compartments so arranged that it would be impossible for any arc to short-circuit from one compartment to another. Each of the feeder switches should also be mounted in its own separate fireproof compartment and preferably controlled electromagnetically from a distance. By adopting electric control from a distance it is possible to combine all the switches required for the generators, feeders, etc., upon a small keyboard under the observation and control of a single operator who will be in a position to have a comprehensive survey of all the measuring and control devices needed for the station, and at the same time be free from danger in case any of the apparatus should fail to perform its work."

The methods outlined at that time were adopted into the art and have not been fundamentally changed since that time, although important improvements have been effected.

With the great increase in size of generator units from 5000 kw. up to 100,000 and 200,000 kw. and of power stations from 20,000 kw. to upwards of a million kw., the switching problem has become more difficult, but the oil switch in its various forms still remains the only type which can successfully handle the high voltages and large currents.

Some idea of the difficult service which is now demanded of switchgear may be obtained from the statement that such switches in large stations are expected successfully to interrupt, without damage to themselves or surrounding apparatus, energy flow amounting to not less than 2½ million kv-a.

However, the concentration of power in the larger systems, the increased size of units, the interconnection of large system, etc., have forced upon the attention of designers such switchgear systems and mechanisms.

Exhaustive researches have been pursued and more intensive efforts made to test every novel principle that could be utilized in circuit interruption. Metal clad, oil-filled switchgear, arranged for installation outdoors, has been developed and promises to be more economical in first cost, with equal or possibly greater reliability in operation.

It has been found that the speed of opening the circuit is of importance in maintaining the stability of electrical apparatus in large and long distance systems. Great improvements have been made in reducing the time of opening the circuit from 20 to 30 cycles to a few cycles, or even as low as a half cycle.

A promising new design is one which is intended to combine the advantages of the magnetic air break switch with those of the oil switch, a switch in which the break takes place in the presence of a magnetic field under oil.

Other forms of magnetic air break switches have been devised which will handle large currents at voltages up to 15,000 or 20,000 with success, and these may replace in many situations the oil switch. However promising the new devices may appear, it would seem that for sometime to come, for the heavy duty of the existing systems, reliance must be placed upon the oil circuit breaker.

A particularly novel principle is involved in the vacuum switch of which models have been made which have actually interrupted 159,000 kv-a. at 48,000 volts, the interruption invariably taking place within a half cycle. If this switch proves to be permanently reliable, as is hoped, it will offer the important economic advantage of eliminating all hazard attending the present use of oil in large quantities.

The past decade has witnessed a rapid growth in automatically operated electric stations. Starting with small substations, containing motor-generators and rotaries, their use has rapidly extended to larger and more complex units. In recent years a number of automatic hydro-electric generator stations have been installed, the latest containing eight 12,500 kv-a. units aggregating 100,000 kw.

All these automatic stations have been found to be reliable and to effect material savings in cost of operation.

Rural Electrification

Central stations during the past few years have made excellent progress in serving rural communities. It is estimated that 500,000 farms are now using electricity for domestic lighting, irrigation, and various purposes, an increase of 2¼ times in five years.

A serious handicap was experienced due to the high cost of reaching and serving scattered rural loads as the cost of low-voltage distribution lines was not economically justified. To connect directly to high-voltage trunk lines (of 66,000 to 110,000 volts) involved expensive circuit breaker and lightning arrester equipment.

This situation has been simplified by the recent development of a new, small transformer step-down substation which permits safe and economic connection directly to the high-voltage transmission lines. This is so designed that its resistance to lightning and system voltage breakdown is greater than the resistance of the high-voltage trunk line itself. In other words, the high-voltage line protects the small station. Oil circuit breaker relays, current transformers and other expensive devices are omitted and a disconnecting expulsion fuse and a current limiting resistor unit installed to protect the high-voltage line. The substation is designed for connection between one conductor of the high-tension line and ground, as the majority of high-voltage lines are operated grounded.

A number of other novel features were developed to effect economy with an unusual degree of reliability.

Electric Household Refrigerator

A most notable illustration of the convenience and flexibility of electric power is to be found in its recent application to household refrigeration. A business of not less than one hundred millions of dollars has arisen in the past few years in supplying several hundred thousand refrigerators for domestic uses in this country.

Incandescent Lamp

The incandescent lamp remains the same simple source of electric lighting, standard the world over. By simplification of types and sizes a better lamp is now sold at a lower price than before the war. In fact, the incandescent lamp is unique in that the retail price of all units is now about half the price which obtained ten years ago. It is well known that the prices of other goods and utilities have advanced considerably since the war, in many cases being two to three times that which formerly obtained.

Vacuum Tube Development

It would unduly lengthen this paper to even sketch in briefest outline the manifold applications based upon our better understanding of that familiar old device, the vacuum tube. Their name is legion—the incandescent lamp, the electric valve or radiotron, the vacuum tube oscillator, the rectifier, the inverted rectifier or thyratron, the pliotron, and so on *ad infinitum*.

In the vacuous space man has discovered ions, protons and electrons, and promptly forced them to do his bidding.

In telephony, the vacuum tube makes possible long distance conversation throughout the country, and it is essential to ocean telephony by radio. It enables conversation to be carried on over power transmission lines and it is a vital element in the marvelous art of radio broadcasting.

It is sufficient to say that the family of vacuum tube devices has already made the most varied and amazing contributions of the many which mark out electrical era. They have already produced economic values beyond accurate computation and profoundly influenced the thought and daily life of the world's inhabitants.

Saturation of Demand for Electric Power

Are we approaching the saturation point in the use of electric power? The phenomenal increase, for example, in the number of customers using electricity which doubled in the last ten years evidently cannot be continued, as over two-thirds of our population now enjoy electricity in their homes, and over three-quarters of the power used in manufacturing is now electrical, and the remaining potential customers are largely rural.

It would therefore appear that, having regard only to the number of customers, the saturation point has been closely approached. The increase in population will furnish new customers, but such increase will not permit the continuation of the rapid expansion of the past decade. Other sources of increased use must be found if history electrically is to repeat itself. Fortunately other means exist.

It is only necessary to increase the amount of electric power used by present customers, a solution clearly appreciated by the leaders of the electrical industry. The records of the power sold by central stations in 1928 show that the average customer in the United States consumed 459 kw-hr. It is undoubtedly possible to greatly increase this consumption. There has been, in fact, a substantial yearly increase for many years.

When one considers, in addition to lighting, the many possible uses of electricity represented by the numerous household appliances whose number is constantly increasing, the field for consumption of electricity instead of approaching saturation, would appear to be almost unlimited. Radio receiving sets and entirely electric refrigerators, for example, represent new and important applications of a very recent date and there still remains the further and more complete electrification of the steam railways of the country.

The cost of electric power to the user is of supreme importance in determining the extent of its use. The record in this respect is excellent, as the price of electric power sold by central stations in the United States has shown constant reduction with the expansion of the business. In fact, according to the National Industrial Conference Board, electricity is the only item in the cost of living which has decreased steadily in price since the World War.

Information as to the cost of production, distribution and use is daily becoming more accurate, and the so-called promotional rate system of charging is being rapidly extended. The information which we have given in this paper furnishes some of the many reasons for our gratifying economic situation.

Judged by the history of its past achievements, its present sound position and its potential developments, a favorable and even brilliant economic future for electric power would seem to be amply assured.

Industrial Progress Made Through Research, and Its Economic Importance

By DR. W. R. WHITNEY
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(A paper delivered at the World Engineering Congress in Tokyo, Japan, October 29–November 7, 1929)

> "We live in a wonderful age. Someone has said that man has made greater advancement in the last hundred years than during his whole previous existence.
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> "The last century was the greatest century of all time in material development, in mechanical invention, in scientific discovery and in the application of natural elements and forces to the uses of man.
>
> "But the discoveries and inventions of the present century indicate that we are moving forward at a pace surpassing all previous records.
>
> "The year 1929 will be another milestone of achievement along the broad road of everlasting time. It should surpass all previous years in material progress. That it shall do so must be our high resolve."

THIS is not a leaf taken from the notebook of some isolated dreamer, but is quoted from the printed menu of the dining car of one of our main railroads. It is thus becoming a rapidly spreading idea.

Moreover, men of every age have had the same impressions and the consequent urge to push forward. Nevertheless, we can safely say that never before has the world's outlook for intelligent appreciation of possibilities been as great as it is today.

Industrial research may be variously defined, but as it is entirely a matter of change, its meaning to different industries will vary with its application. Research is a parent of industrial growth, the other parent being the will to live better. With this simple pedigree, there is no ground for the mystery in which research is sometimes shrouded.

There was a time when most work was actually enforced by hunger or other animal needs. Men, obliged to work or starve, felt the continuous pressure as external, and therefore, distasteful. So there developed an hereditary tendency to dislike extra work. This is happily proving to be a recessive, not a dominant trait, and, moreover, there grew up a persistent counter-trait, sometimes called "monkeying," but better described as interest, inquisitiveness, and constructive appreciation. This counter-trait is successfully opposing inertia, and bringing about effective amelioration, with reduction of physical labor, for it constructs pleasure and happiness out of experiment and research.

Gradually, with the development of experiment, it seemed that man was partaking of the attributes of the Creator. Things in his environment which he did not like, he found that he could change. His efforts, at first directed to his necessities, later turned towards testing the possibilities about him. He began to see that endless discoveries could be made, and while he could never actually create anything new, finding things new to him was eminently gratifying. Rearranging his discoveries became a never ending pleasure, akin to creating.

This rearranging process expanded continually and became the most characteristic mark of mankind. His work on stone to secure weapons for use in the never ending struggle for food, is preserved in what we now call paleolithic artifacts, and this work early showed him the flexibility of the most refractory things, and so encouraged him to increase his questioning, his experiment and the consequent applications. The transference of the warm hide of fur-bearing animals to his own back was another early rearrangement. While his first manufacture was for bare necessities, he later found ways to economize work and to do with mechanical aid many things which had formerly required excessive physical effort. From the very first experiment, everything seemed to favor the principle of change for still further improvement. The more he arranged things to suit him, the more he found that they could be advantageously rearranged.

This growth of creative spirit has reached a point where men now heartily enjoy working as men never had to work before. This work is not solely for food and shelter. That need is often almost forgotten. Men work because of the artistic or creative urge. They have proved it worth while to analyze their environment and to learn by experiment what additional wants and acceptable products can be created. It is no longer a question of surviving, but of better living, and experience has shown that there are unlimited assets in the provisions of creation still entirely untouched.

It is as though we had awakened to a new faith, a faith in the exactitude and invulnerability, the certainty and reliability of countless natural laws, and in the limitlessness and flexibility of their applications. We must hold to the proper use of these laws as the work for our new faith.

As long as the whole effort of an individual was only just sufficient to insure his survival, little could be spent in preparation for more remote interests. And even a pair of protected cave dwellers could not have been advised to divert the efforts of one of them to research before the other could provide living for two. But as time passed, and organizations developed, these grew large enough so that each member was a specialist of some sort. One planted where another reaped, and some produced where others sold.

Nowadays the coördination of effort is such that certain specialists may confine their work entirely to the possibilities of the future. The tendency is to look farther and farther ahead.

In all civilized countries research has had about the same history. It received its earliest impulses from those who spent most time in constructive thinking, and so monks were found producing new knowledge in chemistry and physics and even in heredity. The organized centers of higher education in every country soon became the source of much basic physical knowledge. Time more or less free, and inquisitiveness more or less encouraged, gave opportunity for the discovery and publication of new facts, and the principle of broadcasting new knowledge became fixed in all lands.

We see this in the lives of Joule, Ampere, Ohm, and Volta, for example, where England, France, Germany and Italy respectively are represented, and similarly again in Oersted, Henry, and Huygens, representing Denmark, the United States and Holland. Cavendish, Bertholet, Bunsen, Avogadro, Berzelius, Van't Hoff, and, again, Davy, Pasteur, Liebig, Cannizzaro, Scheele, Van der Waals, are similar groups of representative chemists from the schools of six different countries. Their researches proved to be the foundations on which world industries now tower. But none of these men aimed at the solution of pressing technical problems; though the application of the researches of Pasteur, for example, quickly demonstrated the value of academic studies.

Perhaps in no one case is the effect of long continued academic research more in evidence than in the chemical industry. For a half century the study of organic chemical reactions, without reference to industrial applications, was carried on apparently only for the stimulus which new and exact knowledge gave the minds of men interested in education. Germany in particular, through the researches of countless young doctors of philosophy, gathered a fund of new organic chemical fact upon which enormous and varied chemical industries were established.

The study of physical laws also showed at an ever increasing rate that intelligent experiment, which brought us the steam engine, the spinning frame, the printing press, the electric generator, and thousands of other advances, could reduce hard labor and increase happiness without limit. Each new industry continued to find within itself additional means of improvement. They were all based on the creative instinct of men who were not too heavily hampered.

Still more modern devices and industries well illustrate my point. No one of the many leaders in the automobile industry, for example, started manufacture or continued improvement because of the hunger urge (sometimes, indeed, in spite of it). The race has continued along the promising and endless road of appreciation not under the goad of necessity, but under the beckoning and growing light of understanding. Call this the creative urge or the encouraged inquisitiveness of a changeable animal, the direction and the outcome are the same. We easily fix it into our conception of what is right.

It now runs counter to our instincts to neglect buried treasures. Our experience assures us of an infinite wealth of still undeveloped science. The indifference of millions of people is completely offset by the inquisitiveness and appreciation of individuals. The minds of some have got so far along in variety of specialization and creative will that there need be no end to industrial research.

The experience of those first free-moving cells which came together in the favoring warmth of ocean depths and found those particular functions which each could best perform in the new organism, is copied today in human organizations. Thus we speak of the "increasing functional efficiency of highly specialized units in the division of labor in society" with the same words which were applied to the colony which first developed into a jellyfish. In this respect the industrial plant still resembles the simplest known living plant.

There is some danger of over-popularizing industrial research and also of overdoing the use of the term. The result of attracting special attention to research may be to suggest something essentially false, like a general panacea for work or a cure for all economic ills, and so induce unprepared people to undertake ill-advised work. The excessive demand for scientists in very recent years has indicated such misconceptions.

We overdo the use of the term "industrial research" when we apply it, for example, to the testing of materials in order to check up on specifications. That it is not. It is something designed to discover untested materials and processes, to bring about better use of old materials, to reveal new wants, create new desires and actually predetermine new needs. One might even say that its aim is to perpetuate dissatisfaction with things as they have been and insure open ways to unlimited change. It is continually digging out of the universe new things recognized easily, after the event, as indispensible. One of its aims is to anticipate and predetermine our wishes, so that established manufacturers may, by improving methods or products, continue to grow.

It is a matter of experience that most manufactured articles are sooner or later superseded by others. The new may be entirely different from the old, or may differ only in the method of production, but the successful manufacturers are those who are prepared to change one or both of these criteria. There is no inherent reason why a manufacturing organization need disintegrate merely because a particular product which it once produced is displaced by something better. There are firms which still manufacture the tintypes of years ago, the tallow candles, the ox-yokes and the tin bathtubs, but if they are also making the photographic films, the electric lamps, the farm tractors and the porcelain bathtubs they need not suffer extinction.

It is not contended that industrial research is the key to all human improvement, though general research may be. We might even admit that the Greek civilization, over a period of two hundred years, exceeded our own in the apparent interest in all art and in the tendency to live intelligently. But it is for our age to discover and remove the obstructions in the road to better living in the future. In this, industry must help. New engineering involves making and moving everything more quickly and easily, whether it be man's thoughts or the products of factory or soil. This effective shortening of time and distance also helps to obliterate differences in custom and in tongue, and thus eliminates ground for misunderstandings. We ought to anticipate for the whole earth's surface the experience of village development where natural economics and general welfare persist in coöperative peace, and a single constable is also dog-catcher, fire-chief, and postmaster.

Bergson wrote that the essential object of science is to enlarge our influence over things. "Science may be speculative in its form, disinterested in its immediate ends; in other words, we may give it as long a credit as it wants. But however long the day of reckoning may be put off, some time or other the payment must be made. It is always, then, in short, practical utility that science has in view."

One of the leading merchants of the country, Mr. E. A. Filene, of Boston, recently wrote: "The big volume of luxuries, comforts and necessities which we produce and consume has been largely due to research, to an application of the same scientific methods in the conduct of business as have been so successful in medicine, biology, physics and astronomy." In other words, specialists advanced our knowledge by careful experiment, and today, in our production and consumption of luxuries, comforts, and necessities, we are scientifically more active than ever before.

Medicine, always the product of experiment, has become more and more orderly. Never was there a time when new chemical compounds and applications of new principles were being so generally studied; and new ones beget others. Biology, with its researches in the growing cell, has enormously increased our understanding of living processes even to the mechanism of heredity. It has placed in man's hands new instruments for an extensive line of useful researches, and never has there been so much value in sight. Physics, through relatively simple experiments, has done more in the past two decades to inform us about the nature and properties of matter than in all preceding time. It has been marked by theory and speculation, but largely by a kind of speculation which was at once capable of material investigation, and now there is more promise than ever. Astronomy, a science which has always called for the utmost credulity, has advanced through relatively simple researches supporting exceptionally radical speculations, and with its increasing dimensions it still supplies principles of similitude which are exceedingly fertile and necessary for interpreting modern scientific conceptions of matter; and here, too, is more of interest just within reach than at any time. And so it must be with industries. They will develop not alone greater economies and more complete substitution of mechanical power for human effort, but they will disclose with new discoveries those unexpected utilities which come from the interlocking of new knowledge in different fields.

A brief reference to the growth of industrial research in America may not be out of place. To a great extent any history depends on who writes it, but certain general facts of American growth are obvious. Doing new things intelligently ought to come from research. The general sequence is very old. But as mechanically empowered industry may be called a development of the last century, so organized industrial research may be attributed to the present century. The United States has taken part in both activities. At the beginning of this century there were practically no industrial research laboratories in the United States, and the word "research" was almost exclusively confined to college and university. Now a recent report of the National Research Council lists a thousand research laboratories independent of colleges and government bureaus. Three hundred were listed in 1920. This connotes a change that is affecting industry as definitely as the introduction of steam, for intelligent interest in industrial research is by no means confined to the United States.

It would not be difficult to picture the influence of organized research in such active industries as aëronautics, electricity, automobiles or radio. These are entirely modern. Here many youthful and inquisitive minds see the light and feel the creative force. Their work has been well advertised. But in looking over the laboratories of the country one sees how it has also been with less popular things. For example, as organic chemical knowledge progressed a very few explorers attacked the chemistry and physics of cellulose. Here was one of nature's most widely spread products. It seemed to be so complex, when compared to the simple compounds which chemists had already understood and synthetized, that few were bold enough to attack it. But Tollens, Fremy, Ost, Schwalbe, Chardonnet, and Cross and Beven were such pioneers, and now we see that wood pulp, the cellulose mine, is continually yielding new products. Its chemistry and physics are being widely studied. It is being applied for sound insulation, and for insulation of heat. It is used as a cotton substitute in high grade paper, and even modern silk is made of it. It is used in explosives, and also for non-inflammable movie films. It threatens to displace bone and ivory, except where they are actually born, and it is displacing the vehicles of varnishes and paints. These new cellulose products did not come through an increase in the rate of grinding wood, nor because trees began to grow faster. They did not come because pulp tonnage produced new markets. They came because the researches of purely inquiring minds supplied new knowledge and altered points of view. The industry was lifted by new levers. The leverage was the work of research chemists who began devoting their lives to the study of cellulose. They purified it, they dissolved it. They tried every conceivable reaction with it. They hydrolyzed it, they nitrated, sulphided and sulphated it. They fermented it, they coagulated it, they precipitated it. They studied it as a colloid and they studied it as a crystalloid. They studied each new cellulose compound as to any possible interest it might have. They established an extensive literature covering several decades of careful observations. It is not surprising that there should be many possibilities of service in what, in radio, would be called "new hook-ups" of the established knowledge. This illustration may not be as standardized as some that might be taken from modern electrical developments, but I use it as a conservative and generally applicable example of industrial research as it is actually carried out.

A generally similar effect of research can be found on many sides, but it seems usually true that the more modern the industry the more extensive is the application of research to it. Coal, iron, cotton, wool, leather, and ceramics seem less thoroughly cultivated from the research standpoint than such corresponding, but slightly more modern subjects as petroleum, aluminum, cellulose, dyes, rubber, and paint. In the former group the efforts to produce in large quantities apparently postponed the pressure of research work.

But even with the older industries many marked effects of research have resulted. The Corning Glass Company has given us glass cooking utensils which the new knowledge of controlled expansion coefficients made possible, and very recently paraffined paper bottles have been introduced in New York to reduce the cost and increase the cleanliness of bottled milk Countless new solvents are now being produced through researches on petroleum, and by the study of gaseous combustion, an enormous field of cutting and welding steel has been developed.

Modern research applied to the paints, varnishes and enamels used by industries interested in automobiles, radio sets, and power refrigerators has produced many more satisfactory products than were the earlier metal coverings. The modern field of the photographic industry somewhat resembles radio in being based entirely on active research. Every year brings out new photographic improvements, the silent drama, the talking movie, the colored movie, and soon the talking colored movie, while the radio finds new generating and receiving systems through continuous researches in electronics.

It is easy to speculate in industrial futures, but to do it carelessly is not industrial research. Every industry interested in future growth should devote to scientific research a small fraction of its profits. But what fraction shall it be? Experience and not experts should decide that, bearing in mind the possibility of a greater investment by competitors.

Attached as I have long been to an industry in which active research is a habit, I cannot fix in my mind any upper limit to useful novelty, though I can for the rate at which it may be sought. For that reason I am interested in the statement of Haldane, the biochemist: "It is quite likely that after a golden age of happiness and peace, during which all the immediately available benefits of science will be realized, mankind will very gradually disintegrate." This seems based on bad arithmetic. I hope that the golden age of happiness and peace will forever be the one just ahead of the present and that for which man can forever prepare. There are several hundred thousand years of experience which warrant this hope. I think that the world can no more realize "all the immediately available benefits of science" than one could realize the volume or capacity of an infinite pyramid by starting blindly to creep along one of its outer edges.

But if we confine our estimate of the importance of industrial research to a survey of material benefits, we lose sight of what may well be its supreme achievement. For industrial research affects our creeds. Biology shows us how far we have come from the amœba, and shows us, too, the kind of coöperative effort which insured the advance. We may therefore believe that when research is utilized by all industries, natural by-products will be further mental development, more serviceable idealism, fuller understanding among peoples, and better direction of the affairs of nations.

What is being learned from science, specialized for industrial needs even of sordid kinds (experienced but perhaps not always recognized), is that impartial and truthful experiment is more serviceable than any amount of emotional persistency or unemotional fixity. While scientific research continues to extend naturally, and men feel the value of newly acquired material knowledge and truth, the possibilities of improvement in more important human relations than industry, through painstaking, impartial analysis and constructive, forward-looking synthesis, will be realized.

Economic Results of Railway Electrification

Advances in Steam Locomotive Construction—Four Basic Reasons for Electrification—Analysis of Specific Electrifications, by Reasons and Results—Saving Shown in Every Item of Operation

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(A paper delivered at the World Power Conference in Tokyo, Japan, October 29–November 7, 1929)

WHEN giving consideration to the economic future of power for use in transportation, one must first take cognizance of the history of the art, its progress up to the present time, and the effects of modernization in the type of power applied to this service. From the beginning of the railroad industry, by the invention of the steam locomotive in the year 1802, we can rapidly proceed to about the year 1890, until which time no thought had been given to a different type of motive power. This interval was marked only by a continuous increase in size and changes in the details of construction of these power units. Apparently no difficulty was experienced in meeting the constant augmentation in train weights; and while the lack of power was felt on heavy grades, the limitation of track capacity was far in the future. The demand for higher speeds under this condition had not arrived. The art of electric traction, at the latter date mentioned, was then in its infancy, while the Diesel engine and steam turbine had not as yet come into existence. A few of the tramway systems had substituted electric power for horses, but little if any consideration had been given to the steam railroad field as a potential user. Before the advent of electricity, the steam locomotive reigned in an undisputed field. Since then, however, the electric locomotive, the multiple-unit car, the Diesel oil-electric locomotive, and the gas-electric car have disputed its rights on an ever-increasing scale. The many operating or economic advantages of these more modern transportation units insure their greater application in the steam-locomotive field.

During the past thirty years, and especially in the last half of this period, the basic costs of fuel and labor have been constantly rising. These facts, in themselves, have stimulated economy.

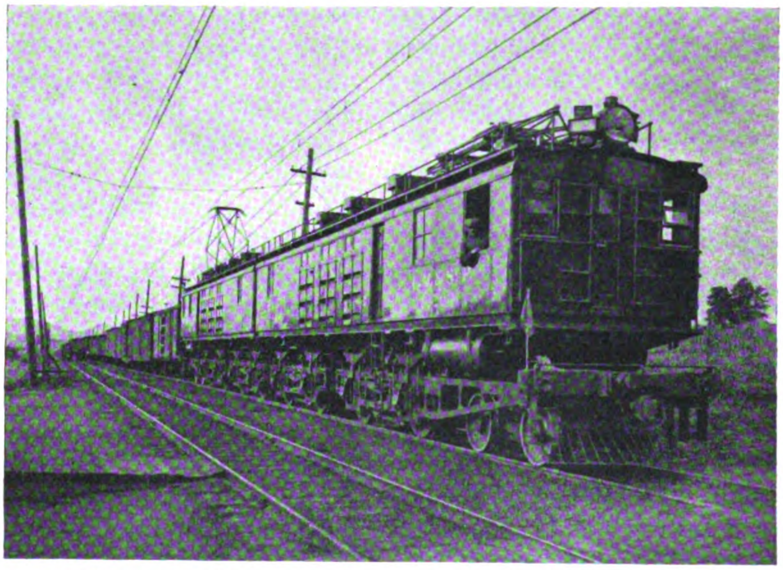

Fig. 1. 288-ton 3000-volt D-c. Locomotive and Freight Train Descending 2 Per Cent Grade in the Rocky Mountains

The trains have become longer and heavier; and the speeds have increased. To meet these conditions, the weight and capacity of steam locomotives have constantly increased; the weight of the largest (with tender) now exceeding 1,000,000 lb. and having a capacity of more than 4000 hp. Furthermore every device of human ingenuity has been added to promote economy—superheaters, feedwater heaters, mechanical stokers, automatic cut-off regulators, etc. Rails and bridges have been made heavier to carry these larger motive-power units. Each year brings nearer the time when train weights and speeds must remain constant or else another type of motive power must be substituted.

As might be expected, the nearer the steam locomotive reaches its natural economic limitations, the more rapidly electrifications are taking place; their scope and locations being determined by the various factors involved.

In analyzing the primary reasons for substituting electricity for steam, the justifications may be segregated into four distinct cases as follows:

Case (1). Where long tunnels are necessary to shorten the line, reduce grades and curvature, or to enter the terminals.

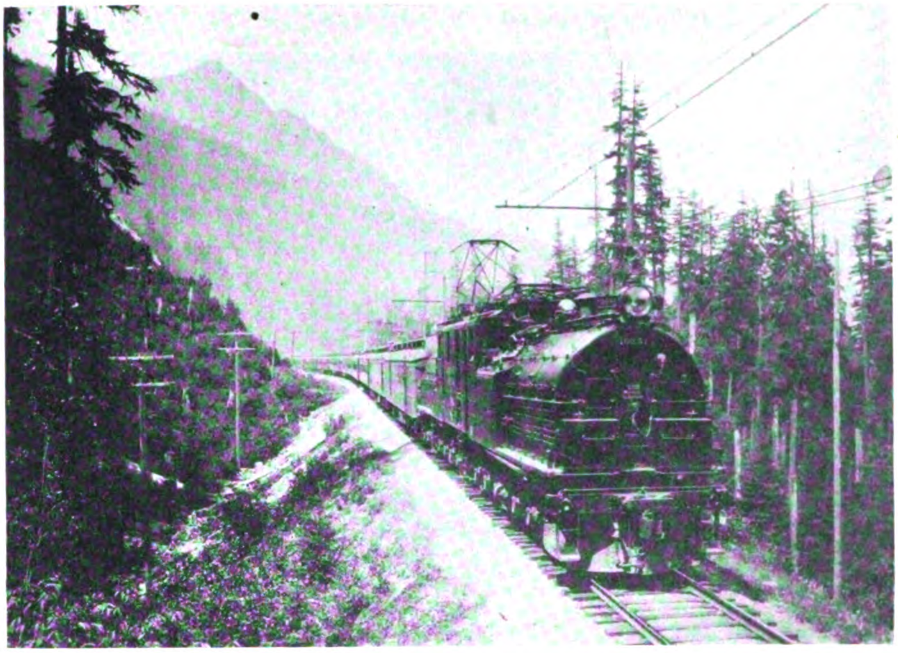

Fig. 2. Transcontinental Passenger Train *Olympian* of the Chicago, Milwaukee, St. Paul & Pacific Railroad, Hauled by 260-ton 3000-volt D-c. Passenger Locomotive in the Cascade Mountains

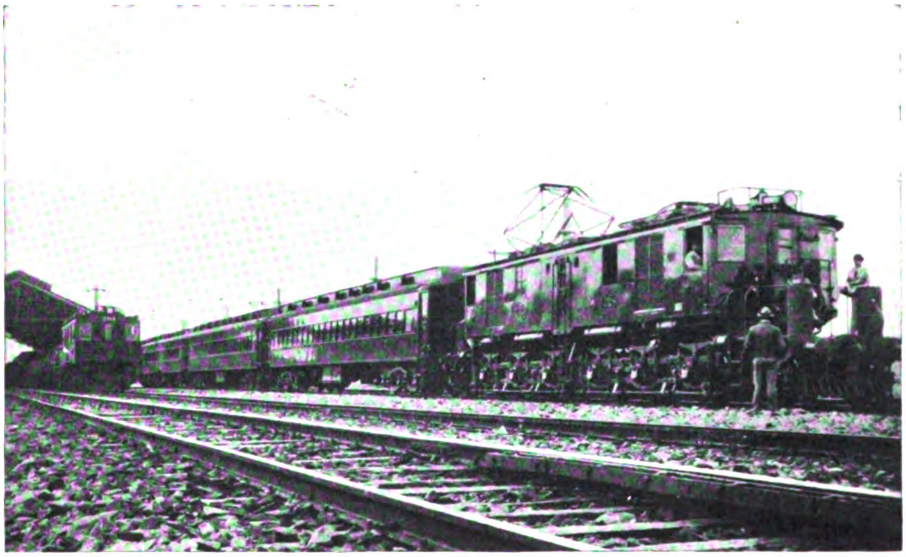

Fig. 3. 147-ton 3000-volt D-c. Passenger Locomotive with Main-line Train on the Paulista Railway (Brazil)

Case (2). Where smoke conditions at terminals becomes a menace to the public welfare.

Case (3). Where the physical limitations of the steam locomotives are such as to prevent the economical hauling of desired train weights at relatively high speeds on heavy grades. In this connection, track capacity is an important factor.

Case (4). Where calculations of the relative costs of fuel, electric energy, and labor indicate that a proper return can be secured on capital invested in electrical equipment.

Unfortunately railroad statistics do not, in every instance, permit of the comparison of steam and electric actual operating costs, especially where the section under consideration is comparatively short and the expenses thus only form a part of those applying to a railroad division. Then, also, for Cases (1) and (2) the value attributable to electrification, while large in some instances, is of an intangible character reflecting in part to the outside railroad operations and in part to extraneous interests. When tunnel, terminal, and grade electrifications are extended in the natural course of events to embrace adjacent track areas, then the true economic value of electrification can be better measured.

It can hardly be said that economic considerations were entirely controlling in the electrification of the Baltimore and Ohio Railroad tunnel in the city of Baltimore, which was effected in 1894 and represents the first installation of this character in the United States; the same is true of the Paris-Orleans Railroad tunnel between Austerlitz and Quai d'Orsay station; the Michigan Central Railroad tunnel at Detroit; the terminal electrifications in New York and Philadelphia; and other projects of like character. The departure from steam, with its attending smoke, gases, and noise, in some cases made possible the desired form of access to the city depots and in others met the requirements of public ordinanaces affecting the urban population as a whole.

Passing to Case (3), we enter a zone for electrification where the compensating results may be considered, in the strict economic sense, as applicable wholly and entirely to the operating company.

On long heavy grades the steam locomotive first demonstrated its limitations, both physically and economically. True, the weight of the trailing train was not limited if sufficient weight were placed on the locomotive driving wheels, but the speeds with the heaviest Mallet compound engines available—of which two, three, and even four were coupled in a single train—were insufficient to meet the schedules desired and in some cases limited the track capacity to a point below that necessary for handling the available tonnage. The railroads were therefore confronted with the problem of either subtsituting

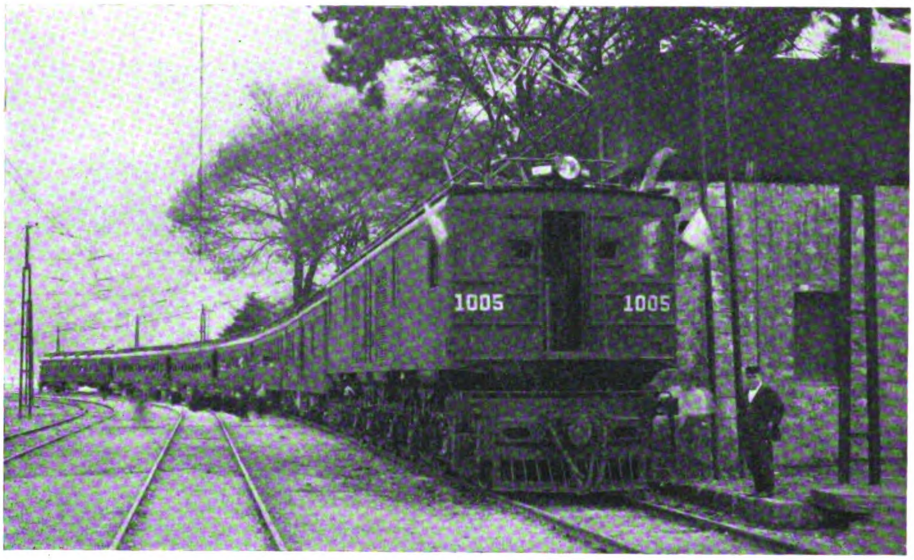

Fig. 4. 150-ton Six-axle Locomotive with Passenger Train on the Mexican Railway Company's Lines

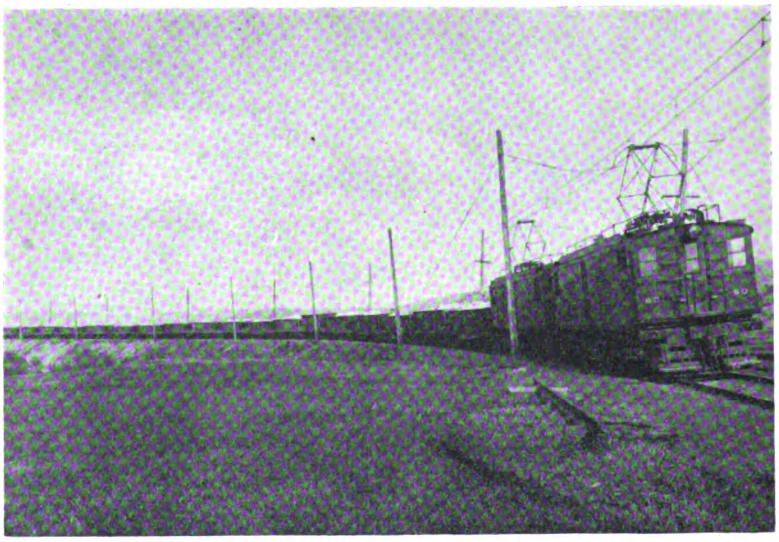

Fig. 5. Ore Train on 1.1 Per Cent Grade of the Butte, Anaconda & Pacific Railway, Handled by Two 80-ton 2400-volt D-c. Locomotives

a form of power unit having a greater output for a given weight or increasing the number of tracks, with corresponding tunnel bore, etc. at a prohibitive expense. Another consideration of importance, not affecting track capacity, was the fact that the greater the number of steam locomotives for a given section of track, and the larger the horsepower requirements, the more the savings by electrification if power could be secured at a reasonable figure as compared to the price of fuel. Then also, the steam locomotives, working at maximum capacity on the up grades and braking on the down grades, required a maintenance expense out of proportion to that for locomotives of the type used for reasonably level grade service to handle trains of a similar weight over like distances.

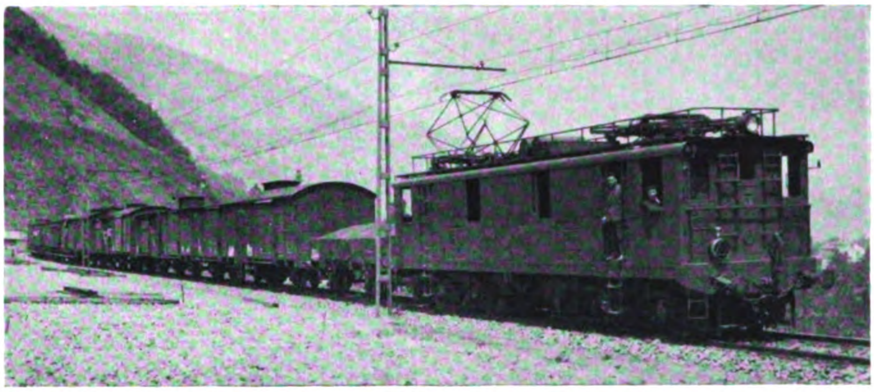

Fig. 6. 90-ton 3000-volt D-c. Locomotive and Train on Two Per Cent Grade of Spanish Northern Railway at Cobertoria

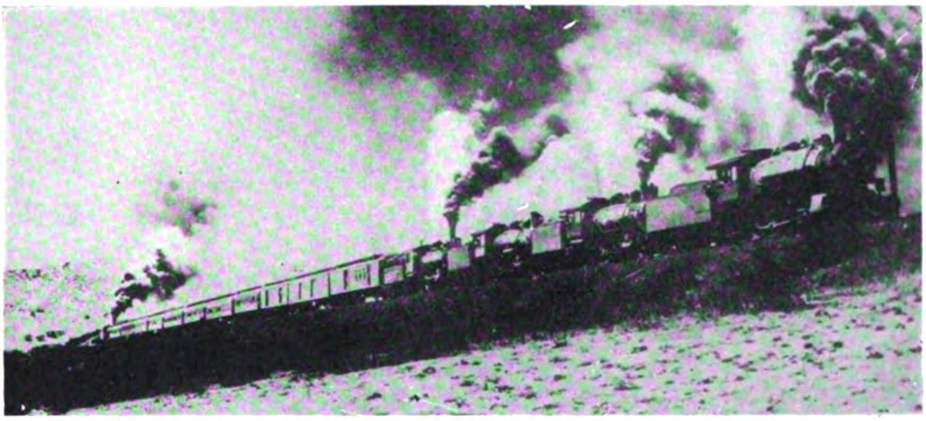

Fig. 7. Eleven-car Passenger Train Being Handled by Five Steam Locomotives on Four Per Cent Grade of the Denver & Rio Grande Railroad at Soldiers Summit (Utah)

The reasons cited in the foregoing paragraph were predominant in the decisions to electrify the Butte, Anaconda and Pacific Railway (1913); the Chicago, Milwaukee, St. Paul and Pacific Railroad (1915); the Paulista Railway (1921); the Spanish Northern Railway (1923); and the Mexican Railway (1925) as well as many others.

In each of the installations cited, the geographic location of the property was such as to place it in a zone where fuel had a relatively high cost. This condition naturally tended to increase the savings affected by electrification, the magnitude of which may be realized from Tables I to V. A saving is shown in every item attributable to operation.

In the case of the Butte, Anaconda & Pacific Railway (Table I), a total of 158,917,720 ton-miles were hauled by steam in the 1913 period and 172,855,856 ton-miles in 1914 by electric locomotives.

The total cost of the electrification was **$1,201,000,** which included seventeen 80-ton locomotives, **4000 kw.** in substation capacity, and about 90 miles of single-track overhead system. The saving shown therefore represents approximately 22.4 per cent on the gross investment, without taking credit for the increased tonnage handled.

TABLE I
BUTTE, ANACONDA & PACIFIC RAILWAY
Steam and Electric Operating Costs

	Steam 1913	Electric 1914	Per Cent Decrease
Fuel and power	$315,235	$164,509	47.81
Repairs	124,788	92,278	26.05
Enginemen's wages	104,461	71,225	31.81
Trainmen's wages	147,632	116,486	21.10
Engine-house expenses	29,908	18,638	37.68
Water	4,954	1,194	75.90
Lubricants	9,751	4,942	49.30
Other supplies	5,823	4,552	21.83
	$742,552	$473,824	36.20

In the case of the Chicago, Milwaukee, St. Paul & Pacific Railroad (Table II), the substation operating expense and maintenance, also the maintenance of the transmission and trolley lines, are included in the power cost. The steam figures are based upon a total of 2,178,613,000 ton-miles and the electric on 2,247,102,000 ton-miles.

The total net cost of the electrification was $15,625,000, which covered a total of 648 route-miles of single-track line with the necessary switching facilities. The actual savings over steam operation for the first ten years after electrification were calculated to be $19,000,000, which figure will bear comparison to the net investment.

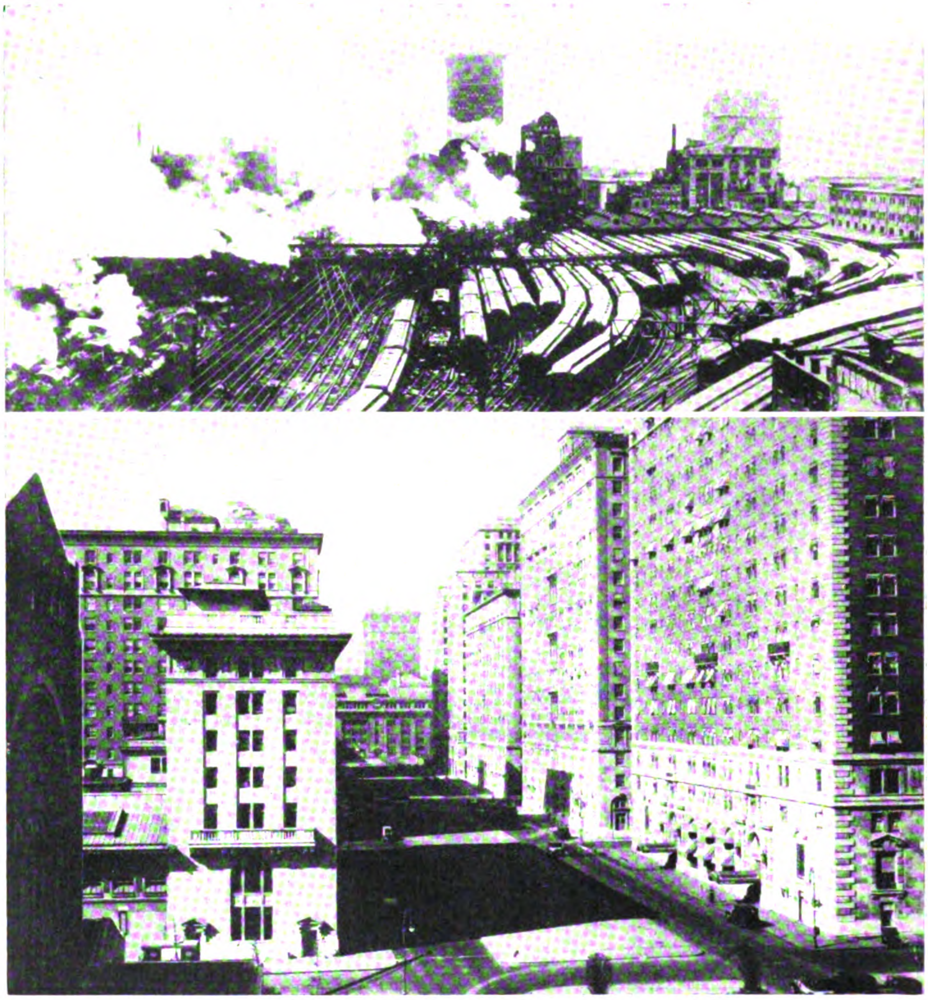

Fig. 8. Views of Grand Central Terminal Area, New York Central Railroad, from 50th Street; Above in 1906 Before Electrification, and Below in 1926. (Note Belmont Hotel in center of each picture

TABLE II
CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD
Steam and Electric Operating Costs

	Steam 1915 Adjusted to 1923	Electric 1923	Per cent Decrease
Fuel and power	$1,920,178	$1,358,529	29.2
Repairs	1,540,027	526,676	65.7
Enginemen's wages	890,032	463,945	47.8
Trainmen's wages	838,765	483,955	42.3
Engine-house expense	303,120	118,895	60.8
Water	82,685	......	100.0
Lubricants	26,541	22,265	16.1
Other supplies	35,722	*33,738	5.6
	$5,637,070	$3,008,003	46.6

*Includes passenger train heating.

In the case of the Paulista Railway (Table III), the figures show a comparison for the same period between an electrified section and a steam-operated

TABLE III
PAULISTA RAILWAY
Steam and Electric Operating Costs

	Steam 1927	Electric 1927	Per Cent Decrease
Fuel and power	$920,718	$192,286*	79.2
Locomotive repairs	142,009	24,076	83.1
Train crew and engine-house expense	401,260	98,109	75.5
Lubricants	26,733	5,421	79.6
Waste and miscellaneous	75,203	26,680	64.5
	$1,565,923	$346,572	77.9

*Includes operation and maintenance of substation and overhead system.

section of similar characteristics and traffic. The gross tonnage, is however, reduced to that for the electrified section, which is 531,470,124 tons.

The total cost of the electrification approximated $4,000,000, which included 20 locomotives, three substations, 83 miles of overhead distribution system, and about 60 miles of duplicate transmission lines. The annual savings of $1,219,351 therefore represents a return of approximately 30.5 per cent on the total investment.

In the case of the Spanish Northern Railway (Table IV), total trailing tonnage in each instance approximated 92,600,000 ton-miles. The items of water, lubricants, and other supplies are not included in the table as figures to cover them were not available.

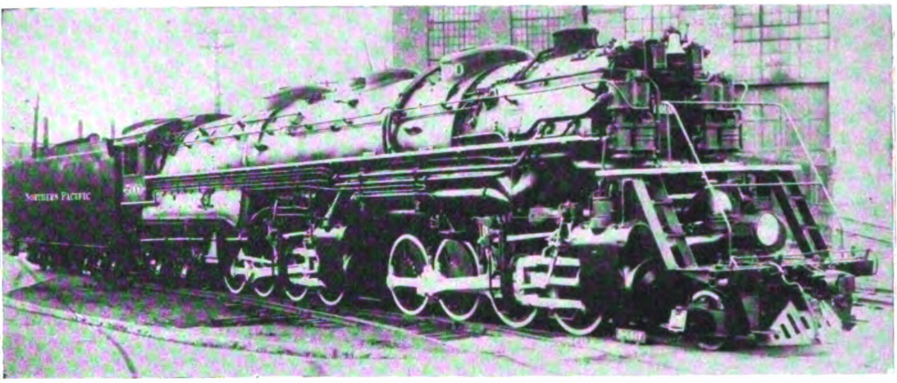

Fig. 9. Latest Type Mallet Locomotive Recently Delivered to the Northern Pacific Railway. Total weight of engine with tender 1,116,000 lb.

Fuel is taken at the average price of $8.18 per metric ton delivered on the tender and electric energy at $0.015 per kw-hr. delivered at one of the substations from which it is carried over a railroad transmission line to the second substation.

A total of twelve 90-ton electric locomotives replaced thirty steam locomotives.

The total cost of the electrification was $2,601,000; therefore the approximate return on the investment was 14.3 per cent.

In the case of the Mexican Railway (Table V), the figures are based upon the tonnage for 1928 with steam figures for 1921 adjusted accordingly.

The total cost of the electrification was $2,485,340, which included ten 150-ton locomotives, one substation, and about thirty route-miles of overhead system. The annual saving of $663,348 therefore represents approximately 26.7 per cent on the gross investment.

TABLE IV

SPANISH NORTHERN RAILWAY

Steam and Electric Operating Costs

	Steam 1924	Electric 1925	Per cent Decrease
Fuel and power..........	$370,700	$159,760*	60.0
Repairs: including engine-house expense..........	131,500	34,800	73.5
Enginemen and trainmen..	78,400	29,200	62.8
	$580,600	$223,700	61.4

*Includes operation and maintenance of substations and overhead system.

TABLE V

MEXICAN RAILWAY

Steam and Electric Operating Costs

	Steam 1921 Adjusted to 1928	Electric 1928	Per cent Decrease
Fuel and power..........	$300,834	$204,900*	31.9
Locomotive repairs.......	408,354	35,814	91.2
Enginemen's wages.......	185,946	87,390	53.0
Trainmen's wages........	130,332	64,326	50.8
Engine-house expenses....	23,388	11,670	50.1
Lubricants...............	19,146	552	97.3
	$1,068,000	$404,652	62.1

*Includes operating and maintenance of substations and overhead system.

The generally satisfactory operating results that attended the tunnel and terminal electrifications, and these combined with the great reduction in expenses for hauling trains on heavy grades, provided the necessary incentive to extend the electrified zones and also to study the application of a similar practice to the more or less level lines.

So, in recent years we find electrification extended to the Paris-Orleans Railway, the Midi Railway, and the Paris, Lyons & Mediterranean Railway in France; the Spanish Northern Railway, Barcelona suburban zone in Spain; the Benevento-Foggia and Nord Milano lines in Italy; the South African Railway; the Great Indian Peninsula Railway; the Moroccan Railway; the Japanese Government Railways; and other systems in practically every country on the globe. The compelling note in most of these projects has related to the high cost of fuel and the ability to purchase electric energy at a low price from water-power generating stations.

Generally speaking, electrification has lagged in the United States since the termination of the World War. The reasons are manifold, but the predominant one is undoubtedly the plentiful fuel supply at comparatively low cost, which eliminates to some degree the possibility of the remarkable savings effected by electrifications in other countries. Taking the past decade, however, important progress along these lines is found in the Pennsylvania Railroad suburban electrification at Philadelphia; the Illinois Central Railroad suburban electrification at Chicago; the Great Northern Railway electrification over the Cascade Mountains (75 miles); and the extension of existing electrification zones.

Today a new era has arisen, insofar as electrifications in the United States are concerned. The Pennsylvania Railroad has completed its plans for electrifying from Washington to New York, involving almost 1000 miles of track. The Delaware, Lackawanna & Western Railroad has commenced work on its New York suburban electrification. The Reading Company is making plans for its Philadelphia suburban electrification. The New York Central Railroad is now making studies for the completion of its main line electrification to Buffalo, involving over 3000 miles of track. Thus in a few years the electrified mileage of railroads in the United States will probably be quadrupled.

This completes the brief and abridged history of the electric art as applied to main-line transportation systems. Its value in this article rests as a guide to the future.

In the interim between partial and complete electrification on the individual systems, the Diesel-electric locomotive and the gas-electric car will play a part. Many switching yards and branch lines can economically use equipment of this character because the traffic per unit of track length is insufficient to compensate for the cost of an overhead system that would otherwise have to be employed, and the substations to feed it. Also the relatively small amounts of power required, the absence of diversity in the load-factor, and other adverse elements would affect deleteriously the price of purchased power. When, however, these same switching yards and branch lines become a part of an electrified system, it will undoubtedly be in the interest of standardization and economy to operate them in the same manner as the main lines.

Diesel-electric locomotives and gas-electric cars, in the field of their particular application where large horsepower capacities are not required, show decided economies over steam-locomotive practice, both in the matter of fuel cost and repairs. The zenith of their practical use is somewhere in the future.

The turbine locomotive, upon which experiments have been conducted in Germany and England, deserves a brief mention in passing as it introduces the fuel saving factor in steam-locomotive design, thereby automatically reducing boiler dimensions for a given output. Further practical use must demonstrate whether the advantages so obtained are more than offset in the matter of space, weight, cost, maintenance, etc. In any event the turbine locomotive must be treated as merely a change in design of the steam locomotive and not, in any sense, as a substitute for electrification.

If the history of power units for railroad transportation, as herein summarized, is correct, then the electric locomotive with its attendant overhead system and substations will be the predominant factor in the industry on an ever-increasing scale.

To meet the requirements introduced by this prediction, it is expected that electric energy for operating the trains will be acquired at suitable distribution points from the large power and lighting networks, and that the generating and transmission companies will deliver such energy to the railroad trolley without requiring the railroad to consider such conversion units as might be necessary. The railroad will thus be able to concentrate on its one product—"Transportation."

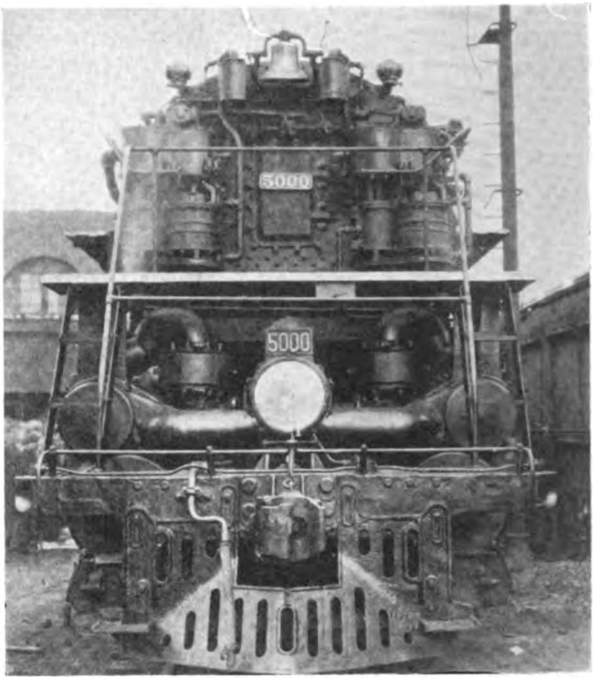

Fig. 10. End View of Mallet Locomotive No. 5000 Recently Delivered to Northern Pacific Railway

The writer, from his analysis of the attendant conditions, summarizes his conclusions as follows:

(1). That the steam locomotive will predominate for many years.

(2). That the Diesel oil-electric locomotive will be used in increasing quantities.

(3). That the turbine locomotive is still in the experimental stage and that no figures are available to justify its overall economic position.

(4). That electricity is finding an increasingly useful and economic place in the transportation field. As traffic densities on trunk lines and congestion in terminals and yards continue to increase, the economic advantages of electric traction will necessitate the greater use of this form of motive power.

Rolled Steel in the Construction of Electrical Machines

Radical Changes in Construction of Mechanical Parts—Substitution of Rolled Steel for Castings—Ingenuity and Invention Required—Description of Innovations—Advantages

By HENRY G. REIST
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(*A paper delivered at the World Engineering Congress in Tokyo, Japan, October 29–November 7, 1929*)

ONE of the important contributions recently made toward the reduction of cost and and improvement in design of the mechanical parts of rotating electrical apparatus is the substitution of rolled steel fabricated parts for the cast structures that have heretofore been universally employed. This change from castings to rolled material required thought and invention, as it was not simply a case of replacement. New forms of construction had to be developed to use the new material to advantage, to give it a satisfactory appearance, and to design it so that difficult joints in the construction were avoided.

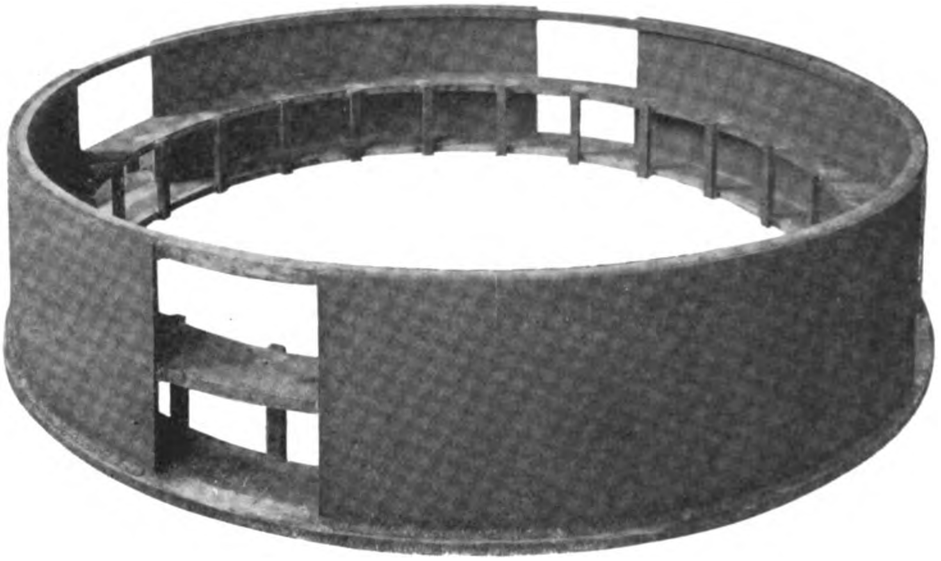

Fig. 1. Steel-plate Stator Frame of an 18-pole 2000-kv-a. 400-r.p.m. 2300-volt Generator

The results of the development of this idea have been far reaching. A number of iron and steel foundries have been closed down, many large machine tools have been eliminated, and the whole manufacturing method for this apparatus has been so changed that fabricating shops have replaced machine shops. The advantages derived from this change in construction are immediately apparent and involve three savings: the saving in time to make the patterns, the saving of the cost of making the patterns, and the saving of the expense of storage and repairs. This last group is no small item because of the large size of the parts involved in some of our modern machines. Moreover, after the metal has been poured into the mold there is no way of being absolutely sure that the casting will not be defective; and the loss and delay occasioned by defective castings is a serious item in the total cost of building electrical machinery. Shrinkage strains in castings are a constant source of worry to designers and the excess metal in the form of risers and finish allowances which must be machined off is an added expense not only because of the extra metal but because of the time required to remove it.

All of the difficulties just enumerated are eliminated by the new forms of construction. Since standard plate and beams are used, the material is readily obtainable and no further development is required to render it suitable for immediate use. The material employed is free from flaws and shrinkage strains, is ductile, works and welds readily, and can easily be cut by a hydrogen flame into segments, circles, or any other desired shape. For many parts these shapes can be fabricated with sufficient accuracy to obviate any need of machine work; and where greater accuracy is required, the amount of material that must be removed is much less than that which has to be taken from castings. The appearance of the fabricated parts can be made neat, as it is a simple matter to remove all scale and roughness by sand blasting, and the resulting surface can be painted without using a filler undercoat

The General Electric Company built fabricated steel frames about 15 years ago when building induction motors used for ship propulsion. In order to keep the weight down, the stator frames were built by using circular-rib steel castings and a thin outer circular shell of sheet steel. These parts were riveted together and formed a satisfactory, but expensive, construction. A fabricated structure was also adopted for building turbine-generator stator frames to avoid a complicated casting subject to casting strains, which occasionally caused some of the ribs to break.

This work was facilitated by improvements in flame cutting of metals and electric welding of steel, which included the development of automatic welding machinery to handle the heavy current arcs employed. An example of the kind of work which was done is shown in a 1400-kv-a. and a 2000-kv-a. vertical generator built in 1924 (Fig. 1), in which the stator frames were made of steel plates. The accompanying pictures and the following text show some of the construction used in carrying out this development.

The frames are built of two or more circular parts, flame cut from steel plates. To the inner edge of these the dovetailed ribs for engaging the punchings are welded; and, to the outer edge, plates rolled to circular form of the correct diameter. On large diameters, the radial circles are made of segments welded to each other. Frames over 12 to 14 ft. in overall diameter must be made from two to four sections to allow them to be shipped. The joints (Fig. 2) between the sections are made between bars that are planed, drilled, and dowelled together before they are a part of the big structure. These pieces are then bolted together and welded into place on the two parts. There is no finishing or fitting between the joints of the large sections, and they always fit perfectly.

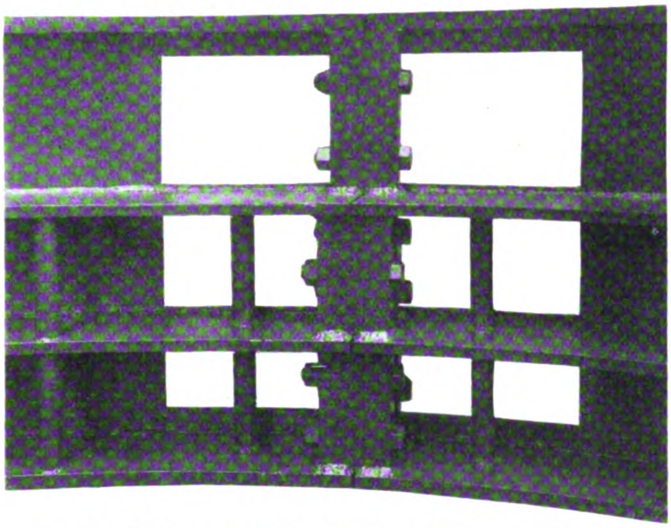
Fig. 2. A Joint in a Steel-plate Stator Frame of a 52-pole 4500-kv-a. 138 ½-r.p.m. 4000-volt Vertical Waterwheel Generator

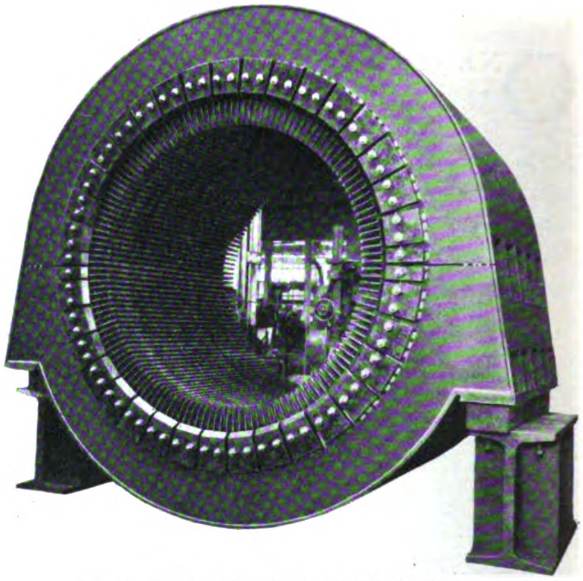
Fig. 3. Stator, with Punchings, of a 50,000 kv-a. Synchronous Condenser

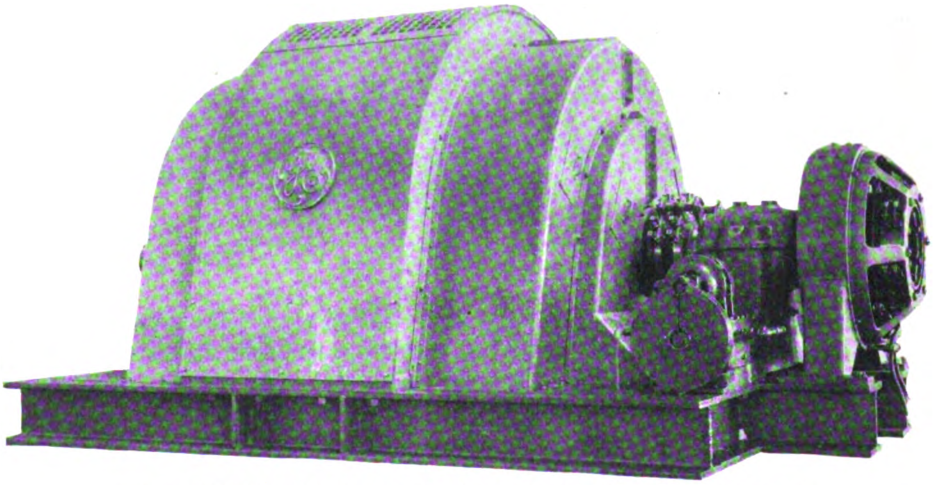
Fig. 4. A 5000-kv-a. Synchronous Condenser with Base Constructed of H Beams

The inside of the frames is relatively smooth and allows a large space for ventilating air to pass around the circumference to openings left in the wrapper plates for the exit of the air. These openings are covered by perforated plates. Fig. 3 shows the stator of a 50,000-kv-a. synchronous condenser and Fig. 4, a smaller condenser, shows the end covers of steel plate and a base constructed from heavy H beams. In Fig. 5, a large frame having a diameter of 37 ft. is shown standing on edge while its deflection was being measured.

The construction of large rotors for salient-pole machines has undergone marked changes. Rotors with a small number of poles in which the laminations extended from the shafts to the poles were formerly confined to about five feet in diameter inside the poles, because that was the limiting width obtainable in plates from $\frac{1}{16}$ to $\frac{1}{8}$-in. thickness. In recent years it has been found practical to punch plates $\frac{3}{16}$ in. to $\frac{5}{16}$ in. thick and the limiting diameter of this type of rotor has been extended to more than 10 ft. (Fig. 6). Formerly, spiders of this diameter were made from steel plates about two inches thick, the slots for receiving the pole dovetails were machined, and the plates were machined all over. For rotors with a moderate number of poles, where the speed is reduced and the stress is less, some of the plates are omitted, the remaining ones being spaced over the length of the poles, thus reducing weight and cost. Fillers are used to make the dovetail slots continuous.

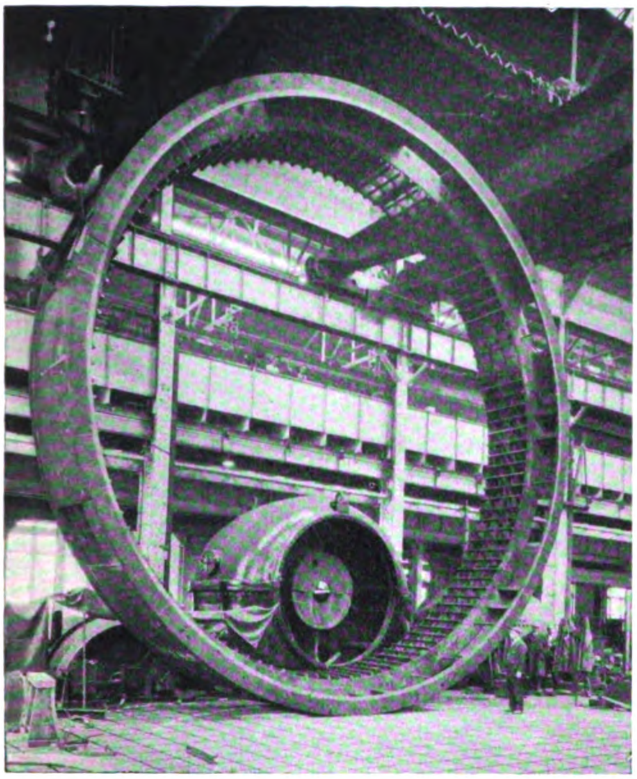

Fig. 5. Stator Frame of an 88-pole, 40,000 kv-a. 81.8-r.p.m. 13,800-volt 0.9-p-f. Waterwheel Generator

The material used in rolled plates of all thicknesses is soft and capable of great elongation. It is free from internal strains; but a defect in one of the plates, should it occur, could be tolerated since only one plate out of many would be involved.

Rotors of slower speed and larger diameters have a center spider which supports a separate rim to which the pole pieces are attached. It is our recent practice to use a rim which is free from the spider. It may be shrunk on the spider or simply built closely around it. The rim is driven by keys or dowels. By placing such drivers in each arm, they act as dowels to keep the rim central when it expands by centrifugal force or from heat. It is a decided advantage to have the rim carry all its load rather than place part of it on the arms. The stresses are then all in tension, instead of being partly in bending. They can also be calculated more easily and accurately. In this design the rim is built up of flat segments punched from sheet iron of $\frac{1}{16}$ to $\frac{5}{16}$ in. thickness. The thicker iron can be obtained in larger pieces than the thin iron and in many cases is to be preferred. These plates are held together by dowel bolts fitting closely in holes punched through the plates. If the work is done carefully, it is not necessary to ream these holes.

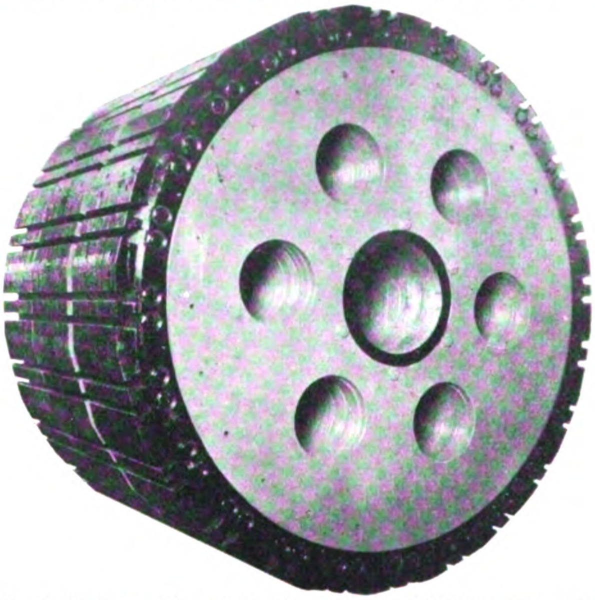

Fig. 6. Steel-plate Rotor Spider for a 24-pole 30,000 kv-a. 300-r.p.m. 11,000-volt Vertical-shaft Waterwheel-driven Generator

Larger structural steel rotor spiders are generally built with cast-iron hubs, to which are bolted two plates or disks to which in turn the arms are bolted (Fig. 7). The arms are made of rolled I beams or, in very large sizes, the arms are built up from plates to the shape of I beams.

Fig. 8 shows the construction of a large spider and rim having a diameter of 29 ft. 9 in. overall. In this case, the rim is a free ring doweled to the arms and is built up from forty-four steel plates one inch thick. Each plate is the full width of the rim, and its length is one-fourth of the circumference. The plates are carefully bent to the proper curve and are held together by radial dowel bolts.

The upper bearing bracket of vertical water wheel-driven generators has to hold the upper end of the shaft central against side thrust and has to support

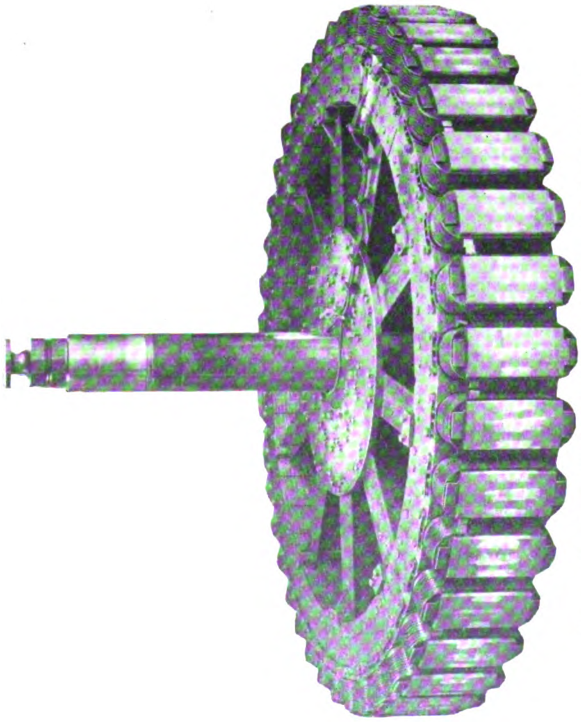

Fig. 7. The Completely-assembled Rotor of a 40-pole, 9400-kv-a. 150-r.p.m. 11,000-volt Vertical Generator

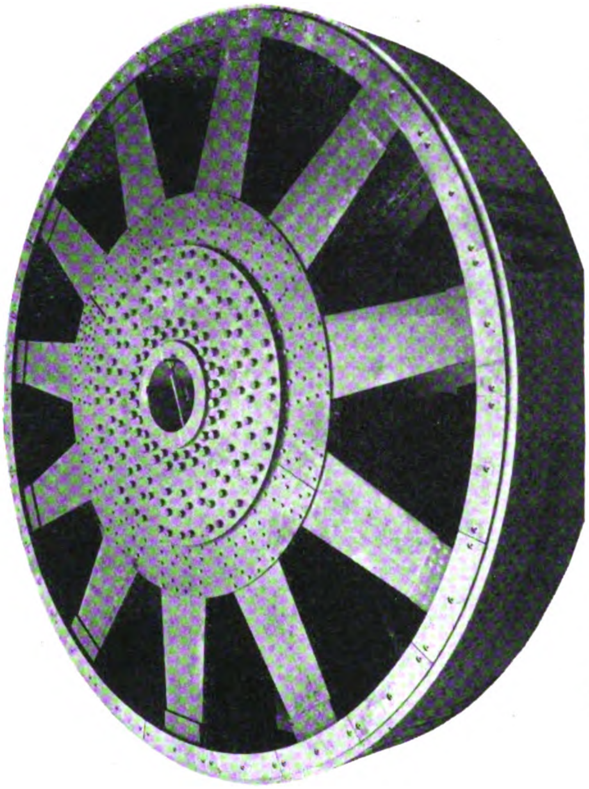

Fig. 8. Rotor Spider for an 88-pole, 40,000-kv-a. 81.8-r.p.m., 13,800-volt Waterwheel-driven Generator

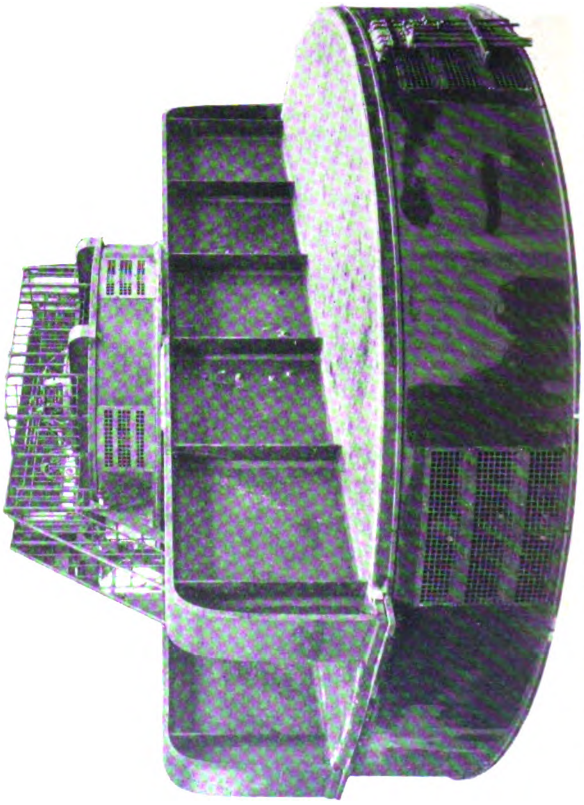

Fig. 9. A 90-pole, 19,000-kv-a. 80-r.p.m. 6900-volt Vertical-shaft Waterwheel-driven Generator with Its 325-kv-a. 575-volt Auxiliary Generator

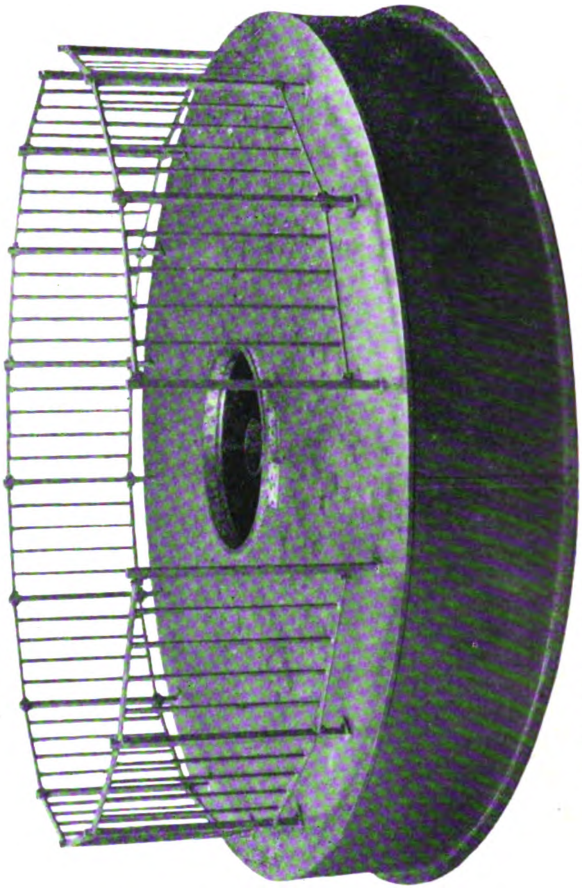

Fig. 10. A View of the Upper Bearing Bracket of a 48-pole 2250-kv-a. 150-r.p.m. 2400-volt Vertical A-c. Generator

the weight of the whole rotating part, as well as the hydraulic thrust of the water wheel on the thrust bearing. One form of structure for this purpose consists of a bridge with deep girders to carry the heavy weight. Rolled girders or I beams serve the purpose well, so long as the depth of beam needed is not greater than 36 in., which is now the maximum that is rolled. It is important for this supporting structure to be rigid and not to be deflected much by its load. With larger loads or greater length of span, it has become necessary to fabricate the beams. Beams have been made for this purpose 6 ft. in depth with a span of 30 ft. These beams consist of central webs, to which top and bottom flanges are welded (Fig. 9). They support a load of 790,000 lb.

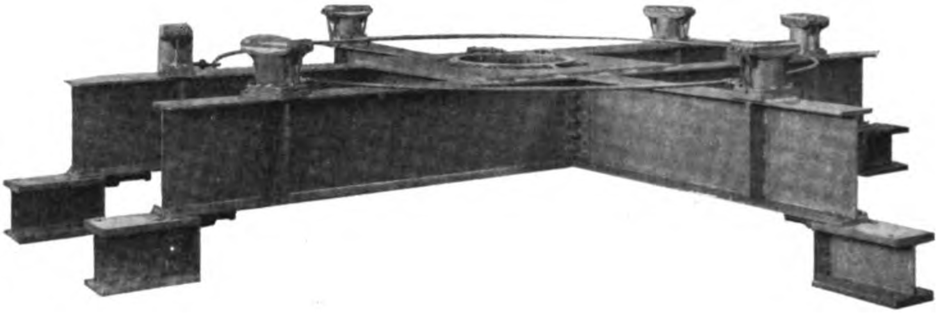

Fig. 11. The Lower Bearing Bracket of a 40-pole, 9400-kv-a., 150-r.p.m. 11,000-volt Generator

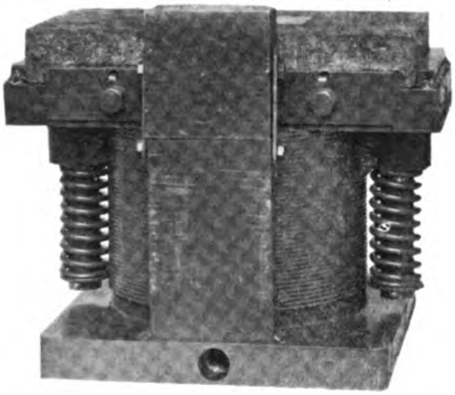

Fig. 12. Hydraulic Brake and Jack Fabricated from Steel Plate, Showing Jacking Block in Place for Supporting Weight of Rotor

As this part of the machine is prominently in view, it has to be designed so that it should have a pleasing appearance. This result is obtained by rounding the upper ends of the beams and by adding a stiffener on the end of the beam, carrying it over the rounded end of the web to meet the top flange. The stiffener has the same width as the top and bottom flanges of the beam.

For smaller diameters, a design of bracket shown in Fig. 10 has been used. This consists of two circular plates, spaced apart by radial webs. Deflections taken on this bracket when loaded indicate that it is very rigid.

The bracket for supporting the lower guide bearing is relatively simple, since it does not carry any great weight at the center and since it is out of the way so that appearance is not very important. It does, however, support the weight of the rotor when the thrust bearing needs attention, but at such times the weight rests at points near the ends of the beams. This structure is usually made of two I beams reaching across the wheel pit and spaced far enough apart to allow the couplings on the shaft to pass between them when the bearing has to be removed. The construction of these brackets is shown in Fig. 11, which also shows the brakes for keeping the rotor from turning due to gate leakage when the water is turned off.

Brake cylinders (Fig. 12) are used also for lifting jacks when the rotor is to be raised off the thrust bearing. They are made of extra-thick steel tubes copper brazed to a base. This is an improvement over the use of steel castings, which many times were porous and would not hold the lifting pressure. The copper brazing is done in a hydrogen furnace by heating the steel parts in contact with copper filings to the melting point of copper. The furnace excludes air with its oxygen and takes the oxygen from any rust on the steel, thus making a perfect braze between the parts.

It has been the purpose of this article to show the change in construction of large electrical machinery that is taking place due to the substitution of fabricated steel for castings and to show also the advantages in quality, time, and cost.

The benefits are so great, and the problems encountered were solved so satisfactorily, that the new type of construction has been adopted by other manufacturers in the United States and in several European countries.

Lightning

PART I

Characteristics Measured in Engineering Units—Laboratory Research—Lightning Generator—H-v. Measurements—Wave Shapes and Polarity—Grading Shields—Poles, Towers, and Structures—Transformers—Transmission Lines

By F. W. PEEK, JR.
General Transformer Engineering Dept., Pittsfield Works
General Electric Company

(A paper delivered at the World Engineering Congress in Tokyo, Japan, October 29–November 7, 1929)

CONSIDERABLE advance has been made during the last five years in the knowledge of lightning and the effects of lightning on transmission lines and apparatus. This progress has been so rapid that the subject may now be said to be on an engineering basis. A good indication of this is that lightning phenomena are expressed in volts, amperes, and time. These results have been brought about largely as the result of research.

The method followed has been to combine field and laboratory work.(1) The work with natural lightning may be divided into two classes:

(*a*). A study of lightning as it appears on transmission lines either by direct hits or induction.

(*b*). A direct study of lightning strokes, the clouds producing them, and the effects of the strokes on rods, etc.

The laboratory work consists of tests on models of buildings, transmission lines, etc., tests on full-size transformers and other apparatus with the reproduction of waves observed in practice; sparkover of insulators, wood poles, gaps, etc.; a study of time lag, etc.

The study at this time indicates the following general characteristics of lightning:

Voltage—order of 100,000,000
Current—order of 100,000 amp.
Energy—order of 4 kw-hr.
Power—order of thousand billion horsepower
Time—order of a few microseconds
Gradient at breakdown—100 kv. per ft.
Charge formed by action of air currents on raindrops.

The time for a large part of the cloud to discharge may vary from one to ten microseconds where appreciable induced voltages occur on transmission lines. The fronts of many induced waves are probably from one to five microseconds. When induced voltages on transmission lines are low, the time may be much longer.

The discharge is generally non-oscillatory. The total energy dissipated in the world by lightning is probably of the order of 1,200,000 kw. continuously (very approximate).

Lightning on Transmission Lines

The wave shape of induced lightning voltages varies over a large range. It seems probable, however, that high-voltage waves have a front reaching crest in a few microseconds or an effective duration above half voltage of 5 to 20 microseconds. This follows because high induced voltages cannot result if the cloud does not discharge very rapidly. The front of the waves depends largely upon the size of the cloud and probably ranges from one to five microseconds for a large number of waves. Low-voltage waves may have a much greater duration. Voltage may occur either by induction or by direct strokes. Direct strokes usually apply voltage rapidly to the line.

The current in the line for a high-voltage traveling wave generally ranges from 2000 to 5000 amp. and is found by dividing the voltage by the surge impedance. Voltages are generally non-oscillatory and the attenuation is very rapid.

Lightning breakdown voltages are always higher than 60-cycle breakdown voltages; the impulse ratio for average high-voltage sparkovers is two.

Induced voltage increases directly with the height of the line and ground wires usually reduce the voltage to about one-half. The maximum voltage is $V=gh\alpha$, but is limited by the lightning arc-over of the insulator. In this formula, $g=100{,}000$ (volts per foot, gradient), $h=$ height of line in feet, and α is a reduction factor $(=\text{or}<1.0)$ depending upon the rate of discharge and the size of the charged cloud over the line.

The transformer insulation should be stronger than the adjacent line insulation.

An approximately lightning-proof line seems feasible.

Laboratory

Voltages higher than any ever observed on lines have been obtained in the laboratory, and design tests have been made on full-size apparatus.

Although progress has been rapid, there is still much to learn and extensive laboratory and field work is planned for the coming year.

The following is an indication of how rapid progress has been during 1928: The time required for a cloud to discharge has been measured by the cathode-ray oscillograph; the wave shape of voltages induced in transmission lines by natural lightning has been recorded by the cathode-ray oscillograph; the attenuation of lightning waves traveling on a transmission line has been determined; natural lightning waves have been reproduced in the laboratory where their effects on transmission lines, insulators, insulation, transformers, and protective apparatus have been studied at will; a lightning generator producing over 5,000,000 volts has been constructed and waves from this generator have been sent over transmission lines to test full-size transformers and other apparatus to determine how to make them highly resistant to lightning; scientific work on the time lag of gaps and insulation has been extended, etc. This list is not complete but will serve to indicate how much progress has been made. The important phases will now be discussed in detail.

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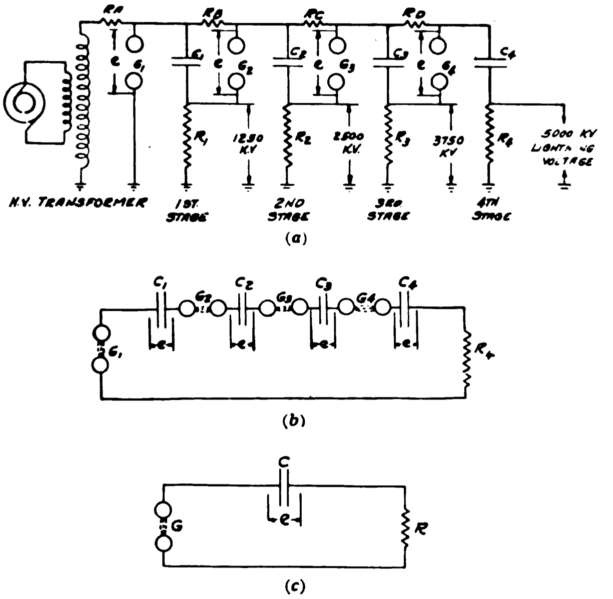
(1) "Lightning and Other Transients on Transmission Lines," F. W. Peek, Jr., *Trans. A.I.E.E.*, vol. 43, 1924, p. 1205.

"Lightning," F. W. Peek, Jr., *Jour. Frank. Inst.*, February, 1925.

"Lightning," *Trans. A.I.E.E.*, vol. 47, 1926, p. 1131.

"Lightning on Transmission Lines," F. W. Peek, Jr., International Conference of Large Electric Systems," Paris, June-July, 1927, No. 56.

"Dielectric Phenomena in High Voltage Engineering," McGraw-Hill, 1929.



(a)

(b)

(c)

Fig. 1. Diagram of Connection for Lightning Generator

LABORATORY RESEARCH

Early Research with the Lightning Generator

An impulse or lightning generator giving voltages of known wave shape was devised about 1913. The first work with this generator was to study the time lag of sparkover, corona, etc. The "microsecond" was used as a unit of time and the "impulse ratio" was found a convenient term to express the ratio of the impulse to the 60-cycle breakdown values. (2)

Later, the lightning generator was almost a direct means of measuring the voltage of lightning. (1) This was done in the following manner and is typical of other similar work on models.

When a lightning flash occurs in the vicinity of a transmission line, a certain percentage of the voltage appears on the line by electrostatic induction. The voltage of the flash cannot be ascertained directly but the voltage induced on the line can be measured. Such voltages were measured on lines. Models were made to scale representing a cloud and an insulated line for certain observed conditions. It was found, for instance, that when a flash occurred from a given model cloud, one per cent of the voltage was induced upon the line and for the particular condition the voltage observed on the actual line was 1,000,000, indicating 100,000,000 as the voltage of this particular lightning flash. (1) The breakdown gradient appears to be 100 kv. per ft. (330 kv. per meter) which is in fair agreement with point-gap sparkover. The protective value of rods for direct strokes, the value of the ground wire, etc., were also studied by means of models.

In what follows, only the most recent work and data will be given in detail, but references will be made to the early work.

The 5,000,000-volt Lightning Generator

In 1927 the laboratory lightning work had progressed so far (1) that it seemed important to increase materially the 2,000,000 volts then available. This increase in voltage was desirable so that full-size apparatus could be tested and results obtained without extrapolation, A 3,600,000-volt generator was built and was in satisfactory operation until January, 1929, when the voltage was increased to 5,000,000. Double the directly generated voltages due to reflection have been measured at the ends of transmission lines.

A new method was developed to obtain the very high voltages. The effect is of adding two, three, four, or more of the original generators (2) in series at the proper instant, so that all of the respective impulse voltages add together. No rectifiers are used. The alternating-current voltage is applied directly to each unit generator. At that instant on the crest of the wave that each unit is fully charged, gap sparkovers take place that connect the generators in series and the impulse occurs. The connections are shown in Fig. 1(*a*). The condensers of the four generators, C_1, C_2, C_3, and C_4 are charged from the transformer to a crest voltage corresponding approximately to the G_2 gap setting. Sparkover occurs on G_1, followed immediately by sparks on G_2, G_3, and G_4. Resistances R_A, R_B, T_C, and R_D, R_1, R_2, and R_3 permit the small 60-cycle charging current to flow but are, in effect, infinite to the very high impulse current. The result is as shown in Fig. 1(*b*). Only three gaps are in series for 3,600,000 kv. and four for 5,000,000 kv. One, two, three, four, or more steps can be used. The wave shape is determined by R, L, and C. Waves varying in duration from a few microseconds to a thousand microseconds have been used. A capacity of at least 0.00034 microfarads is usually used per unit. The maximum energy is about 20,000 watt-seconds. Fig. 1(*c*) shows the original single-unit generator. (2)

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(2) "The Effect of Transient Voltages on Dielectrics," F. W. Peek, Jr., *Trans. A.I.E.E.*, vol. 34, 1915, p. 1857; vol. 38, 1919, p. 1137; vol. 42, 1923, p. 940.

The generator is very satisfactory for very high voltages since the alternating voltage is not rectified, and capacities are charged in multiple and then discharged in series.

Fig. 2 shows a 5,000,000-volt flash from the lightning generator; and Fig. 3 insulators flashing over at 5,000,000 volts. The maximum sparkover distance possible with such a voltage depends upon what wave shape of surge the lightning generator is adjusted to give. With a surge of a very short duration, a sparkover of only 13 ft. can be secured at 5,000,000 volts crest. Longer distances can be broken down with long waves, as will be explained later, as much as 28 ft. being possible with a thousand microsecond wave.

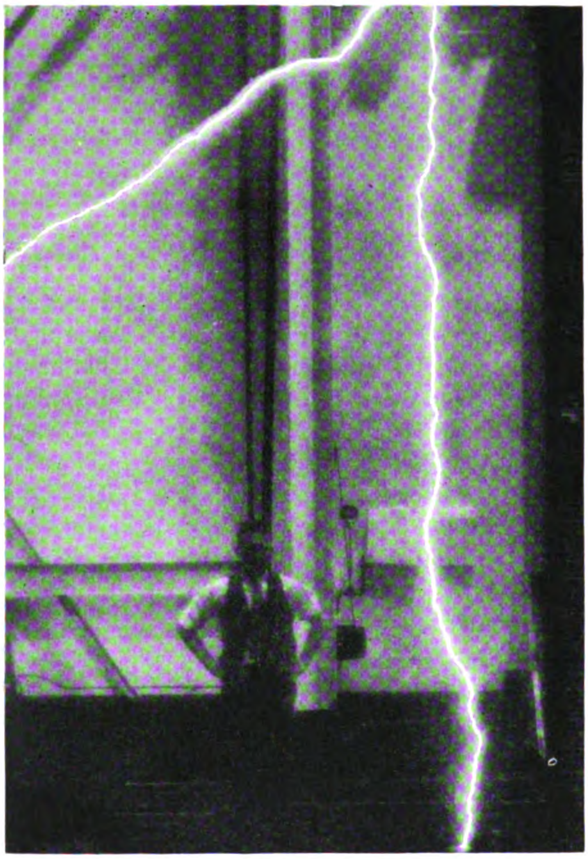

Fig. 2. 5,000,000-volt Lightning Spark Between Needles

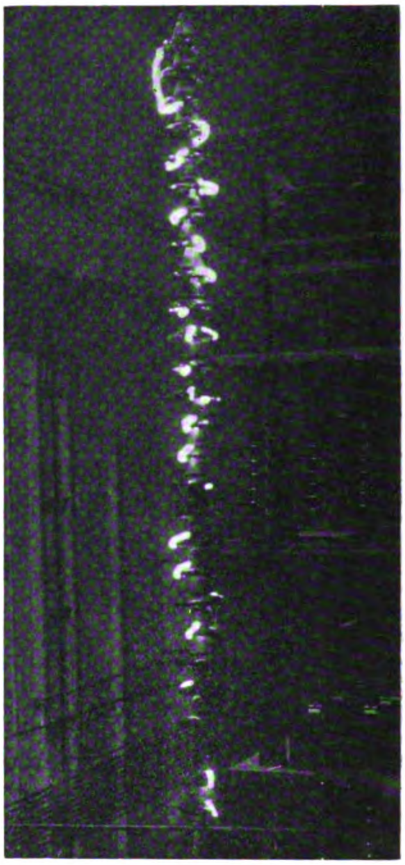

Fig. 3. 5,000,000-volt Lightning Discharge Across a 27-unit String of Suspension Insulators

High-voltage Measurements

In the early work, the voltage measurements were checked in a number of ways. The voltages were first calculated from the circuit arrangement; a check by 100-cm. sphere gaps up to 1500 kv. was made; readings were taken with a surge-voltage recorder;(3) as a final method measurements up to the maximum voltage were made with a capacity potentiometer. Surge-voltage recorder records of 5,000,000 volts from the lightning generator are shown in Fig. 4.

The cathode-ray oscillograph of the DuFour type now affords a means by which oscillograms of transients can be taken readily. In the pioneer work it was necessary to calculate the waves from circuit constants. It is interesting that these oscillograms measuring time in microseconds check the early work.(2) Fig. 5 shows a typical oscillogram. This particular wave reaches its crest in a fraction of a microsecond and then decays to half value in five microseconds. Surges are also frequently measured along a high-frequency timing wave. As a matter of convenience, such waves will be reduced to rectangular coördinates. The wave in Fig. 6 has been used extensively in sparkover tests and is believed to approximate the effects of actual lightning. As will be explained later, this does not mean that the actual lightning wave will always have as steep a front as the waves shown in Figs. 5 and 6. The laboratory tests are usually made so that an arc takes place on the tail. Generally the whole of the wave above half voltage is thus effective. High-voltage insulator sparkovers on transmission lines probably take place on wave fronts of moderate rates of rise. The impulse ratio and the effects are the same. This ratio is usually approximately two. (See Fig. 15, which illustrates how waves with different fronts may have the same impulse ratio.) The impulse ratio is a measure of the effect.

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(3) "The Measurement of Surge Voltages on Transmission Lines Due to Lightning," E. S. Lee and C. M. Foust, *Trans. A.I.E.E.*, 1924, p. 339.

Sparkover of Spheres, Points, and Insulators

The full-line curves in Figs. 7 and 8 give the sparkover voltages for point gaps and insulators with the Pittsfield "standard wave" and other waves, and give a considerable extension of former curves. In making these curves the impulse voltage was increased until sparkover occurred on about half of the applications. The full wave was thus used and sparkover took place on the tail. In addition, curves are given for sparkover on the crests of the waves, which takes place when the applied voltages are considerably higher than those just necessary to cause sparkover. Fig. 9 shows how the lightning sparkover depends upon the length of the insulator string or the spacing of the units with the standard 10-in. (25.4-cm.) unit. The impulse and 60-cycle sparkover values for spheres fall on the same curve.

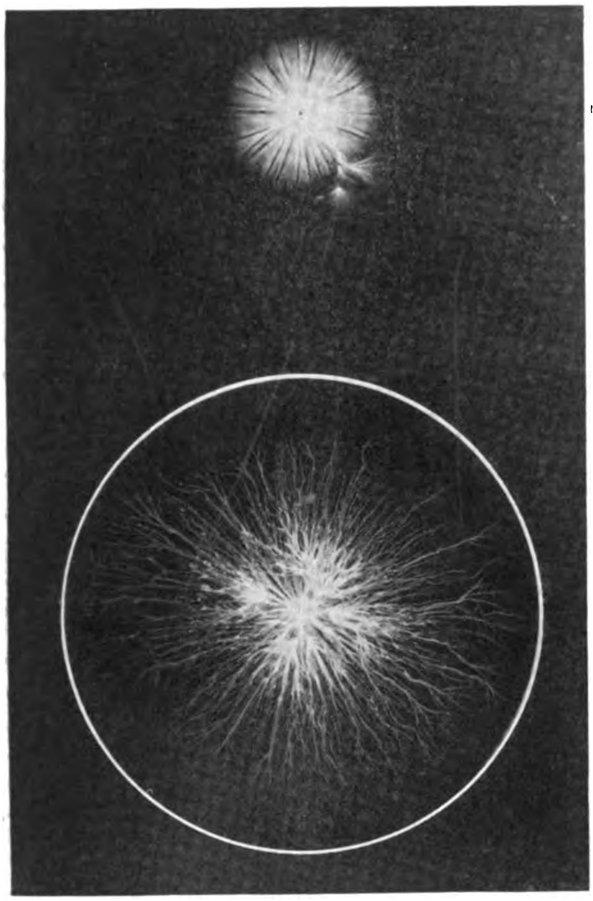

Fig. 4. Surge-voltage Recorder Records of 5,000,000-volt Artificial Lightning

Effect of Wave Shape and Polarity on the Lightning Sparkover

With the exception of gaps between electrodes producing a uniform field, the lightning or impulse sparkover voltage is always higher than the 60-cycle sparkover voltage. The steeper the wave (for sparkover on the front) or the shorter the duration of the transient (for sparkover on the tail), the higher the crest sparkover voltage. The lightning breakdown voltage will thus vary because lightning surges vary. The ratio of the lightning to the 60-cycle crest sparkover voltage is always greater than unity. Some years ago, this was termed the impulse ratio.(2) Under the usual severe lightning conditions in practice insulator sparkover voltages give an impulse ratio of two. This has been well established by comparing the lightning sparkover voltages of insulators as measured in the field by the surge-voltage recorder with the 60-cycle sparkover voltage. The impulse ratio is thus a measure of the effective duration of the wave. It seems reasonable that voltages high enough to cause insulator sparkovers must be of a wave front or effective duration indicated by an impulse ratio of two. This follows because induced voltages on a long line cannot be high unless the cloud discharges very rapidly, thus causing a steep wave; and because direct hits must also apply the voltage rapidly. The wave in Fig. 6 gives approximately an impulse ratio of two. Points measured on transmission lines are indicated on one curve in Fig. 8. The standard laboratory wave was established before the field data were available. Thus, as has been mentioned, the laboratory lightning wave corresponds to the wave causing sparkover and damage in practice, for if the actual lightning waves were of effectively longer duration the impulse voltages could not be so high.

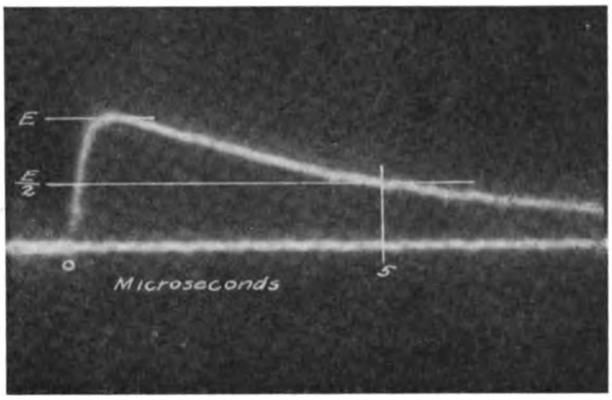

Fig. 5. Five-microsecond Wave of Lightning Generator

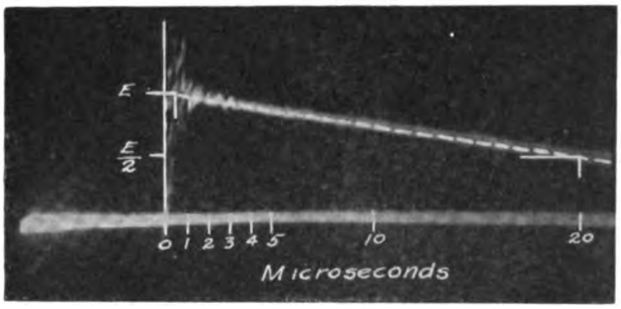

Fig. 6. 20-microsecond Wave of Lightning Generator. Dotted line shows calculated wave

Whether the front or the tail of the wave is the controlling factor in determining the lightning sparkover depends upon the voltage. This is well illustrated by the curves in Fig. 11, representing actual test records on a 19.9-cm. point gap. The same wave shape was used throughout these tests. In the first tests the voltage was increased until sparkover occurred at 50 per cent of the applied impulses. An impulse wave with a crest voltage of 175 kv. was required for breakdown while the 60-cycle crest sparkover value for the same distance was 125 kv. The impulse ratio was accordingly 1.40. The actual sparking points on the wave are indicated by the crosses. An interesting fact was found here probably for the first time; *viz.*, that sparkover actually took place after the tail of the wave had decreased below the 60-cycle value. Apparently the breakdown effect, once started by the overvoltage, continues, so that the spark actually forms after the wave has fallen below the minimum 60-cycle crest sparkover voltage. This is of great theoretical interest, but space does not permit of its further consideration in this article. A wave of 57.5 per cent in excess of the minimum impulse sparkover voltage was next applied to the gap. As can be seen from Fig. 11, sparkover still took place on the tail but at a higher value. Breakdown of the gap occurred on every applied impulse. With 130 per cent excess voltage, sparkover took place practically on the crest of the wave, while at 178 per cent overvoltage, it occurred on the front of the wave. The corresponding impulse ratios for this short gap cover a range from 1.4 to 3.50. The time required for breakdown increases as the applied voltage is decreased. Near the minimum voltage that will cause sparkover, the time varies over a very large range and may even be quite noticeable for spheres. Fig. 12 shows the variation in sparkover voltage with waves of the same front but with 5, 10, and 20-microsecond durations above the 60-cycle sparkover voltage.

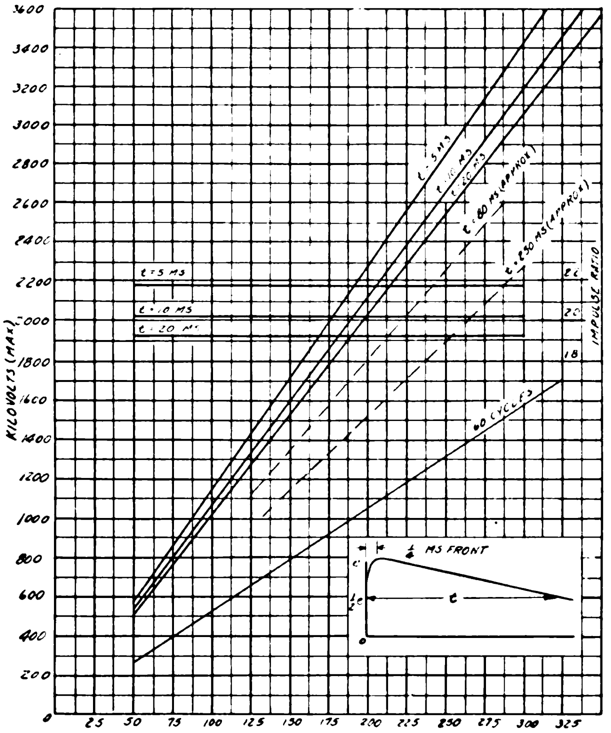

Fig. 7. Point-gap Sparkover for Different Lightning Waves. (Sparkover on tail of wave.) (See Fig. 5 for oscillogram of five-microsecond wave)

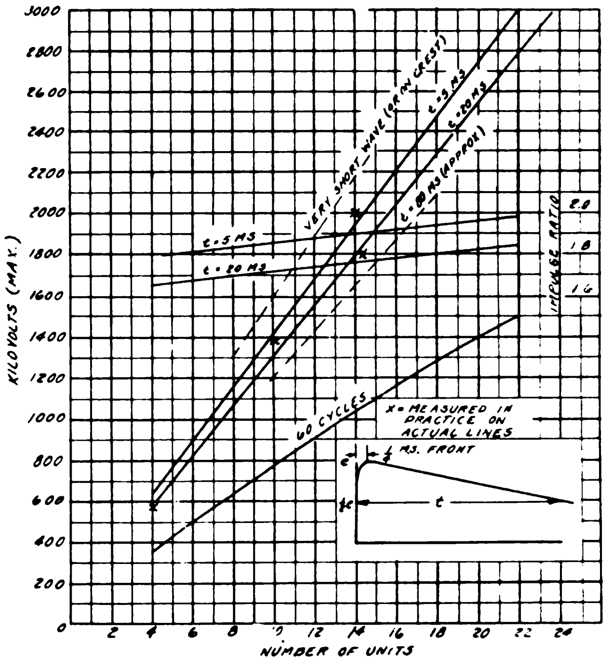

Fig. 8. 60-cycle and Lightning Sparkover Curves of Suspension Insulators for Different Waves. (Sparkover on tail of wave.) (See Fig. 5 for oscillogram of five-microsecond wave)

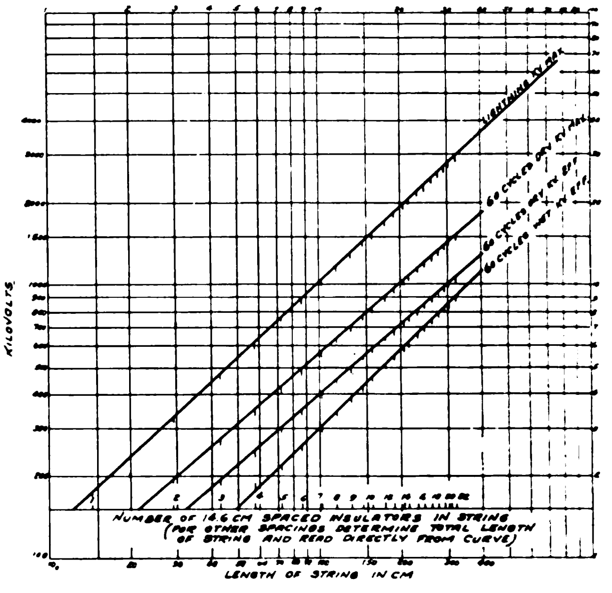

Fig. 9. Lightning and 60-cycle Sparkover for Standard 25.4-cm. Diameter Suspension-type Insulators, Showing Effect of Spacing of Units. (Sparkover on tail of wave.) The lightning wave used reaches its maximum value in about one-quarter of a microsecond and decreases to 50 per cent of its maximum value in 5 microseconds. The length of the string is the actual physical length between center-lines of bolt holes, not actual arcing distance nor creepage distance

Tests were also made with waves rising more or less uniformly at various rates and with breakdowns always occurring on the fronts. The results are shown in Fig. 13. For the gap used in Fig. 13, the impulse sparkover voltage approximately equals the 60-cycle sparkover when the time from application of voltage to complete breakdown is approximately 1000 microseconds. This shows the effect of wave front steepness increasing the sparkover voltage, as previously noted. Fig. 14 shows a typical cathode-ray oscillogram for sparkover on a rising front.

Standard tests in the laboratory are made by gradually increasing the impulse voltage until sparkover occurs on 50 per cent of the applications. The instantaneous breakdown voltage when the front is relatively short then depends largely upon the duration of the tail. This is illustrated in Fig. 15 where the crest voltage is the same for the three waves.

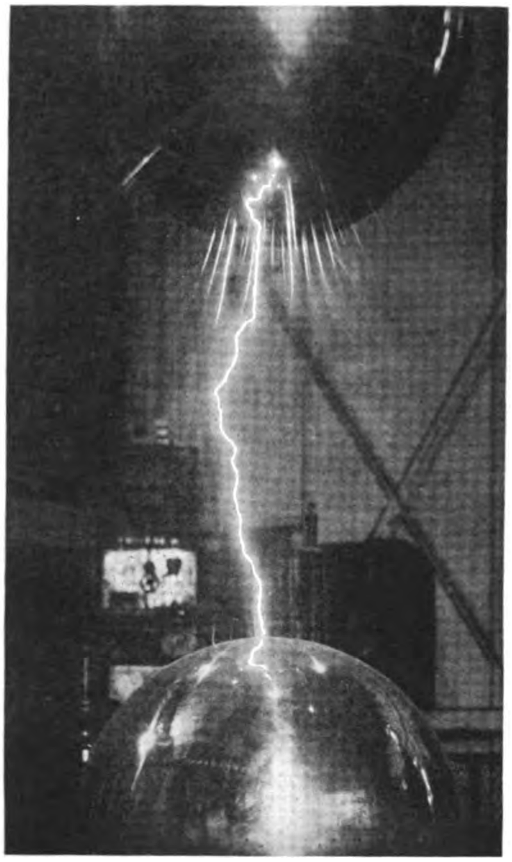

Fig. 10. Lightning Sparkover of 100-cm. Spheres for Wave of Very Short Duration

The results on solid and liquid insulation are approximately the same whether the standard wave, the lightning wave, or a wave with a slowly rising front is used, if the impulse ratio is the same. The three waves are illustrated in Fig. 16. Any of these waves are equally effective for testing purposes.

A gap between spheres has very little time lag if the spacing is not greater than the diameter of the spheres. If the voltage is just at the 60-cycle value there may be a measurable lag for the sphere. In general, however, the impulse ratio is practically unity, and the sphere gap indicates the voltage at the crest of the wave (see Fig. 17). However, because it is generally desirable to know the effective duration of the wave as well as its crest, a "time gap" is necessary in making tests. The suspension insulator is a very good gap for this purpose. An example will best illustrate the use of such a gap. Assume that it is desired to compare the lightning sparkover voltage of two entirely different types of bushings, but that it is not possible to do this in the same laboratory with exactly the same waves. A sphere-gap measurement would give the crest of the wave, but equal sparkover voltages would not indicate equivalent bushings unless the shapes of the waves were known, However, a very good comparison can be obtained by the insulator "time gap" even if the waves differ considerably. This can be done by placing an insulator string in parallel with the bushing, applying impulses, and adding to or removing units from the string until 50 per cent of the sparks occur on each. The equivalent breakdown strength of the bushing is thus obtained in terms of line insulators. Since the impulse ratio of bushings and insulators varies up and down together over a wide range with varying wave shape, the effect of variations due to such differences is eliminated, and a good comparison is obtained. The lightning sparkover voltage of the bushing for any

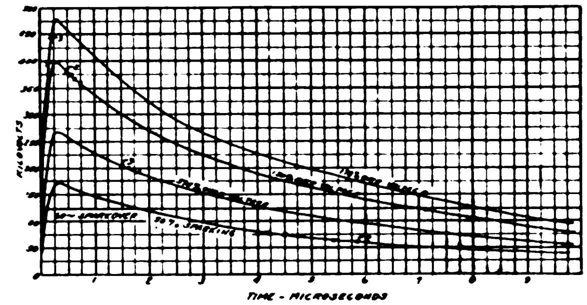

Fig. 11. Sparkover of a 19.9-cm. Point Gap with a Constant Wave Shape at Various Applied Voltages

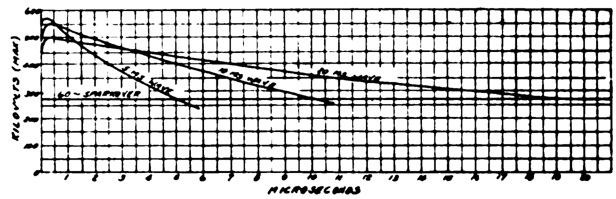

Fig. 12. Sparkover of a 50-cm. Point Gap for Waves of 5, 10, and 20 Microseconds Duration

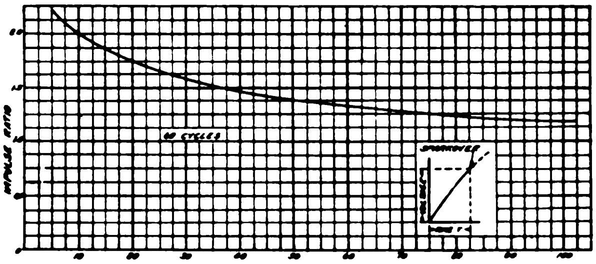

Fig. 13. Sparkover Voltage for Waves Rising Uniformly at Various Rates

particular wave can then be determined from the lightning sparkover curve of the insulator string. The insulator time gap also offers a convenient method for comparing the lightning strength of solid insulation. Since the lightning sparkover varies with the length of the string, it is usually best to express it in terms of the 60-cycle sparkover rather than the number of units, whose spacing may vary. It is possible to use other "time gaps," such as spheres with resistance in series, gaps in oil, etc., but the suspension insulator seems best for practical purposes because it is the "time gap" that limits the voltage on lines.

When the maximum voltage of the lightning impulse causing an insulator sparkover is measured by a sphere or surge-voltage recorder, and the 60-cycle sparkover voltage of the insulator is known, the effective duration of the wave may be obtained. For example, the lightning sparkover of insulator strings measured on the 220-kv. lines of the Pennsylvania Power & Light Company were found to average about 2000 kv. The 60-cycle crest sparkover voltage was about 1000 kv. for these insulators, indicating an impulse ratio of 2.0. The usual impulse ratios of natural lightning vary between 1.8 and 2. In a few cases, impulse ratios as high as 2.7 were obtained. These impulse ratios show that the effective duration varied from one to twenty microseconds, where the effective duration is the time that the voltage is above half voltage or approximately the time above the 60-cycle sparkover. A wave giving an impulse ratio between 1.8 and 2 on line insulation thus represents the average severe field conditions. Thus, the standard laboratory wave established long before measurements were available is confirmed as simulating practical conditions. The crosses on the curve in Fig. 8 give the insulator sparkovers by natural lightning for 4, 10, and 14-unit strings as measured by the surge-voltage recorder. The lightning wave secured on the Pennsylvania Power & Light Company line last summer had a duration above half voltage of about 20 microseconds.

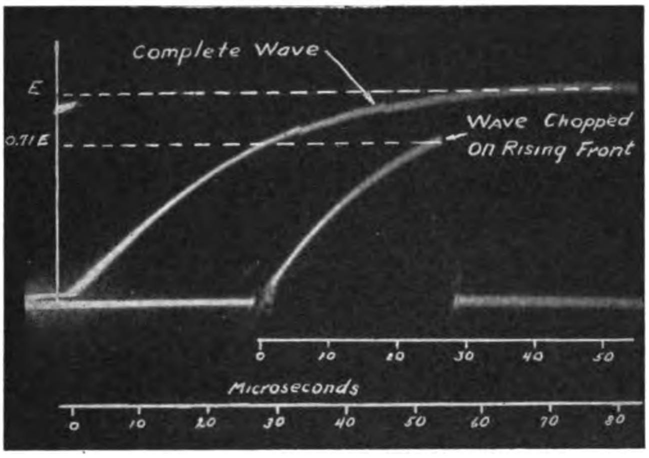

Fig. 14. Cathode-ray Oscillograms. Complete wave and same wave chopped by gap on rising front

In the early work on transients it was found that where dissimilar electrodes were used, lower-voltage sparkovers occurred with the smaller electrodes positive. This has been checked in these recent tests. The greatest differences in voltage result between a point and a plane. With long insulator strings the polarity effect is not appreciable.

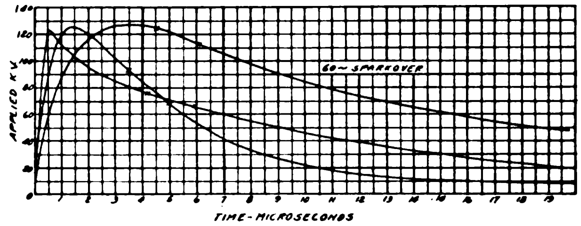

Fig. 15. Effect of Wave Front on Sparkover. 13-cm. point gap. Crosses indicate average sparking range

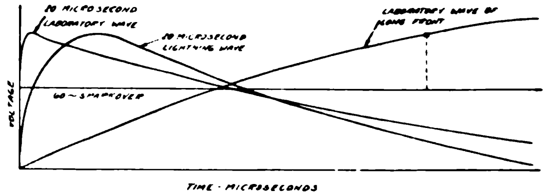
20 MICROSECOND LABORATORY WAVE
20 MICROSECOND LIGHTNING WAVE
LABORATORY WAVE OF LONG FRONT
60 ~ SPARKOVER
VOLTAGE
TIME - MICROSECONDS

Fig. 16. Sparkover Voltage for Various Waves. Sparks occur at same maximum voltage

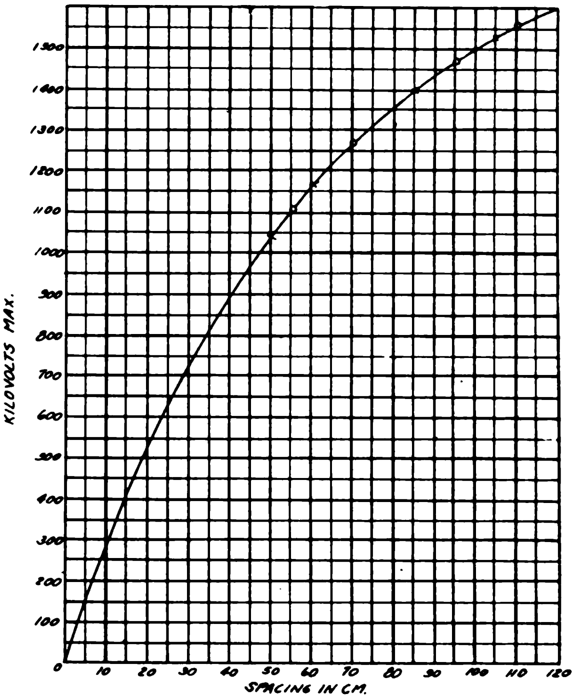

Fig. 17. Lightning Sparkover Curve for Gap Between 100-cm. Diameter Spheres, with One Sphere Grounded

Grading Shield for Line Insulators

Further development at higher voltages on the grading shield seems to make a continuation of the discussion desirable. An important function of the grading shield is to cause even distribution along the string. This considerably strengthens the path along the insulator surfaces to lightning and forces the arc to take place between the rings which may be set for a lightning sparkover voltage higher than that of the non-shielded string. Destructive cascading is thus prevented. The gain in voltage in this way may be as much as 10 to 12 per cent, and can be checked by comparing the lightning sparkover of the non-shielded string as given in Fig. 8 with the needle-gap lightning sparkover for the distance between rings, as given in Fig. 7. For example, take 16 units and 85 in. (216 cm.) between rings. The nonshielded, 16-unit insulator-string sparkover for the 20-microsecond wave (Fig. 8) is 2060 kv.; the needle-gap sparkover for the distance between shields (where the spark takes place on the shielded string) is 2250 kv. (Fig. 7). This indicates an increase of about 10 per cent which is of the order usually found for high voltages. It may be more for very steep waves. That there may be considerable advantage in sparkover voltage for the shielded string was illustrated by a test where an impulse of 80 microseconds duration above the 60-cycle sparkover voltage was symmetrically applied to a shielded and a non-shielded string of equal length connected in parallel. The flashover occurred on the non-shielded string. The difference in sparkover voltage is not appreciable with longer waves. Fig. 18 shows a shielded and non-shielded string. Careful adjustment to prevent cascading must be made at the steeper waves because less time is involved for allowing corona and surface discharges to distribute properly the voltage stresses over the units. Sufficient time is available with slower voltage applications. The gain in voltage with the shield is incidental as its important function is to prevent cascading.

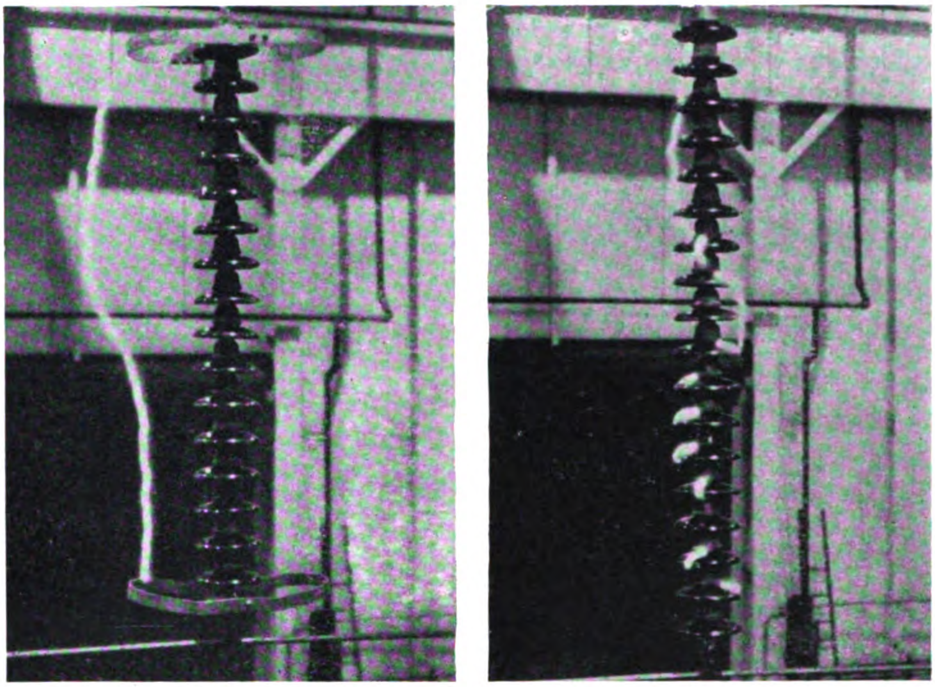
(*a*) (*b*)

Fig. 18. Typical Lightning Arcs on Shielded and Non-shielded Insulator Strings

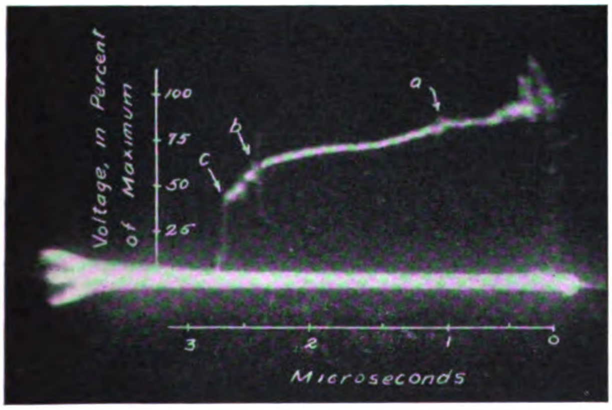

Fig. 19. Cathode-ray Oscillogram of the Successive Breakdown of Units in Non-shielded Insulator String of Three Units
(*a*). Line Unit Sparks Over (*b*). Second Unit Sparks Over
(*c*). Ground Unit Sparks Over

While the sparkover voltage to lightning waves may be increased by the shield, the 60-cycle sparkover voltage may be lowered. This is not a handicap because lightning surges having an impulse ratio of unity and thus corresponding to 60-cycle waves have never been observed in practice. The dry 60-cycle shielded sparkover voltage might be somewhat increased by using *very* large shield surfaces free from sharp ends or points. However, there can be no gain in practice in this way because the large surfaces would be reduced to equivalent "points" in 60-cycle voltages when wet by the first raindrops. Lightning sparkover voltage is not affected by rain.

The oscillogram in Fig. 19 shows the effect of the successive cascading of the units in a non-shielded string. That shields prevent deterioration of the units in a string through improved distribution of voltage stresses is forcibly illustrated in tests. After a few lightning sparkovers, insulator units fail in the non-shielded strings while there are no failures in the shielded strings.

In addition to the actual increase in lightning sparkover voltage, as pointed out, there is also an apparent increase which is probably of more importance. When the energy of the lightning generator is limited, it is necessary to supply a higher voltage to a shielded string to cause sparkover. This apparent increase in sparkover voltage may be of a higher order than the actual increase. The extra voltage must be generated because of the energy dissipated by the "barrel" of corona between the edges of the rings (see Fig. 20). The gain has been observed when the energy available approximated that in an average span and should be an approximate measure of the effect in practice, since there is one shield for each line per span. This energy dissipating effect by corona has been made use of by purposely designing grading rings of flat strap material in place of smooth-surfaced pipes.

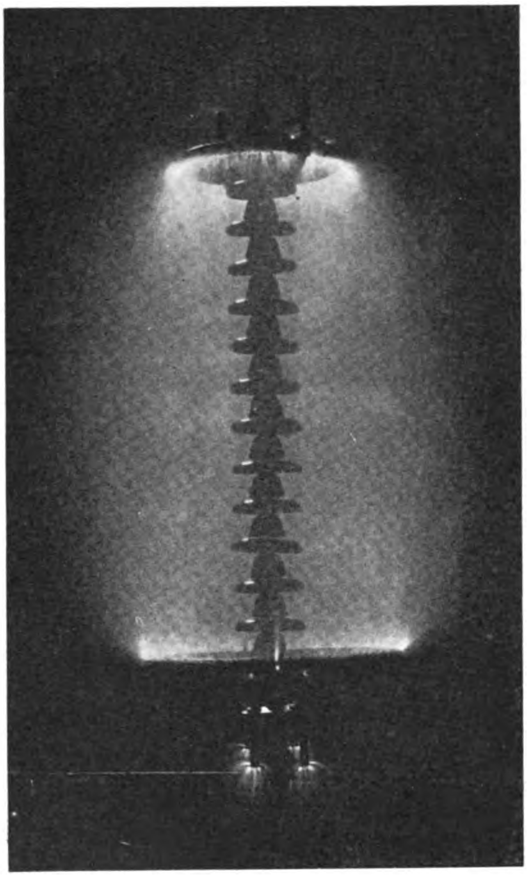

Fig. 20. Dissipation of Lightning Energy by Corona on Insulator Shields

The results of lightning sparkover tests with the strings excited at normal 60-cycle voltages were not different from tests on non-excited strings.

From the standpoint of clearing the dynamic arc, complete, round, or oval rings are highly desirable as a track for the arc when blown by the wind. Anchor points at the ends of a sectionalized shield may cause it to wrap around the string.

Horns cannot prevent cascading without a serious reduction in voltage because they do not properly grade the string. They must be adjusted for a lightning sparkover voltage lower than that of the weak non-shielded string.

Wood Transmission Poles

The insulating value of a wood pole to lightning voltages has been measured up to 5,000,000 volts. The measurements show that the strength of wood poles, of such varying degrees of wetness and dryness that might occur in practice, ranges from 100 to 300 kv. per ft. (330 to 990 kv. per meter); 180 kv. per ft. (590 kv. per meter) is a good average value. Thus a pole 35 ft. (10.7 meters) high with a 5-ft. (1.5-meter) cross-arm would have a lightning sparkover voltage of 12.2×590=7200 kv. The insulator would add very little to a pole of this length. However, when the length of wood in series with the insulator is not over 10 ft. (3 meters) from 75 to 100 per cent of the insulator flashover voltage may be considered as added to that of the wood to comprise the total pole insulation. A practical example of this is a pole made conducting by a lightning rod to prevent splitting, with the insulation depending upon the insulator and cross-arm. In a case of this kind, part of the insulation of the pole could be utilized, and protection from splitting afforded at the same time by placing a gap in series with the lightning rod. To prevent splitting, the 6-3-1 ratio shown in Fig. 21 should be used.

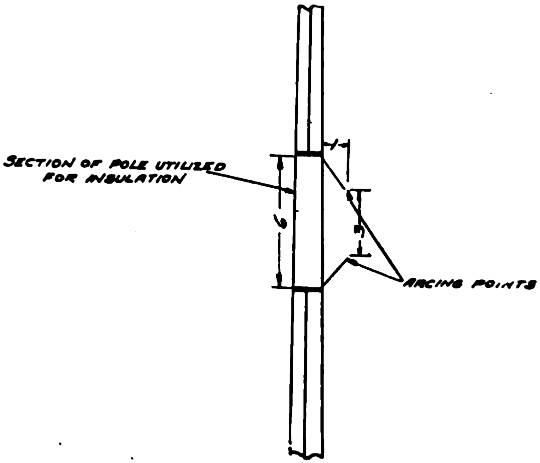

Fig. 21. Proportions for Wood Pole Protective Gap

Whether a pole is wet or dry makes very little difference on the lightning voltage necessary to cause complete flashover. However, when a pole is quite wet, incipient sparks will take place over the insulator string at voltages approximately equivalent to the lightning sparkover voltage of the insulator string. Such simultaneous surface discharges to ground although rather weak in themselves, may create sufficiently ionized paths over the insulators and cross-arm for a power arc between phases to follow. Because of this, reasonable distance between conductors is desirable and conducting braces should be avoided. The cross-arm insulation should be used to the fullest extent.

While wood poles without rods or ground wires may have very high lightning sparkover voltages, there is always a danger of long operating delays due to split and burned poles that cannot be tolerated on important lines. The porcelain insulator is more reliable. However, by the use of gaps, as has been mentioned, part of the insulating value of the wood may be used to advantage on certain secondary lines. Fig. 22 shows a lightning flashover test being made on a 20-ft. (6 meter) pole.

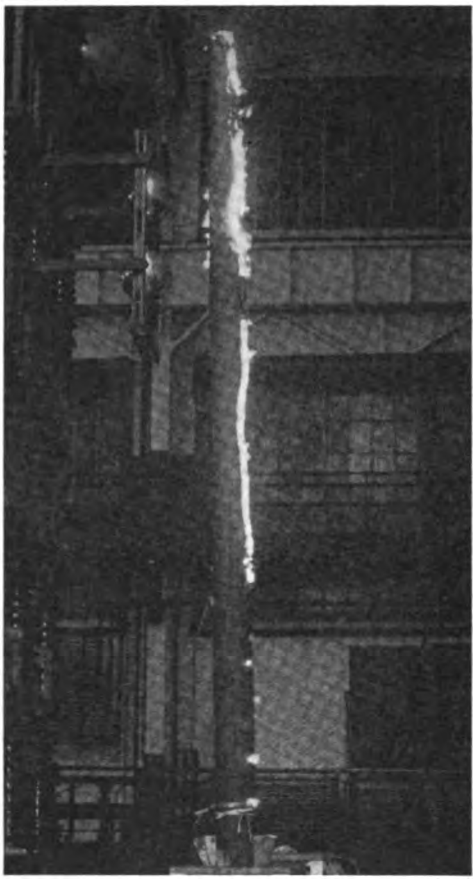

Fig. 22. Lightning Sparkover of a Six-meter Wood Pole

Effect of Tower and Bus Structures on Lightning Voltages

Tests made on models in the laboratory show that the bus structures of outdoor stations should be of material assistance in reducing transient voltages. There are several effects that help. The grounded steel work acts as a very effective ground-wire system which may reduce induced voltages very considerably. Tests on line models built to scale often show as low as one-third voltage when bus structures are added. Full effect of this is not obtained in practice because of the limited physical length of the structures compared to the cloud. A wave traveling to the bus structure would be reduced in voltage owing to the reduction in surge impedance. The massed capacity effect of the bus would prevent high-voltage reflection. The effects in practice should be quite effective for waves chopped short by insulator arcovers. Several extra ground wires of a half mile or more in length extending out from a station should, because of reduction in surge impedance, be very effective in reducing the voltage of incoming waves. On the other hand, tests show that the omission of or reduction in the ground wires at the station causes a rise in voltage.

Tests on models have been very useful in determining the best arrangement of ground wires, the effect of high towers at river crossings, etc. Tests are also under way to determine the practicability of protecting towers from direct strokes by rods.

Effect of Lightning on Insulation and Transformers

The new lightning generator has made possible invaluable studies on full-size transformers and insulation arrangements. It has long been recognized that the internal insulation of a transformer should be stronger than the bushing, while the bushing in turn should be stronger than the adjacent line insulation. Research on transformers has been made by applying lightning waves over a line insulated in the usual way. The general method is to apply gradually increasing impulses until the insulators spark over. Insulator units are then added until either the bushing sparks over or the internal insulation fails. If failures occur internally, the weak points are then strengthened until the flashovers occur on the bushings. The insulator is ideal as a voltage-limiting gap for such tests because it performs the same function in practice, limiting the surges in duration as well as magnitude.

Cathode-ray oscillograph records are taken and the voltage distribution is measured throughout the winding. This last measurement is of extreme importance since it shows that in the usual transformer of either shell or core type the voltage distribution is not constant but varies with steepness and duration of the impulse or the frequency of the transient. High frequencies and steep impulses may cause excessive voltages at any part of the winding. The ideal transformer would be one in which the voltage distribution was the same for all frequencies and wave shapes. Fortunately, it has been possible to accomplish these results by the shielded design, which is an entirely new type. It will not be necessary to go into great detail here because this transformer is described elsewhere.(4) This is probably the greatest advance made in transformers in recent years. Fig. 23 shows the results of tests on the usual transformer and the shielded or non-resonating transformer. In the shielded transformer the impulse and high-frequency distribution are shown to be practically the same as the 60-cycle distribution, as shown by Curve *D*. The transient distribution Curve *C*, which is the envelope of voltages for all high-frequency transients and impulses in the non-shielded transformer, is quite startling.

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(4) "The Influence of Transient Voltages on Transformer Design," K. K. Palueff, *Trans. A.I.E.E.*, July, 1929.
"Lightning Studies of Transformers by Cathode Ray Oscillograph," F. F. Brand and K. K. Palueff, *Trans. A.I.E.E.*, July, 1929.

Curve *A* shows the distribution of voltage at the first instant that a lightning impulse strikes the usual transformer. The winding acts as if open-circuited, the distribution is controlled by the capacitance and the voltage is localized on the end. Later, sections of the winding oscillate and the voltage distribution is represented by Curve *B*. By a series of such oscillations the distribution finally reaches Curve *D*. These curves were obtained by applying all types of impulses and oscillations over a wide range of frequency to transformers and measuring the voltage distribution by means of gaps at frequent intervals along the winding. Cathode-ray oscillograph records were also taken, typical examples of which are given in Figs. 24, 25, and 26. In Fig. 23 a comparison of Curves *A*, *B*, and *C* with *D* shows that the shield reduces local transient voltages as much as 80 to 1 and that excessive lightning voltage stresses in the usual or non-shielded transformer may occur anywhere in the winding, depending upon the wave. It is thus difficult to insulate for all conditions. In the shielded or non-resonating winding, free from localized stresses under all waves, the strength is as definite as an insulator flashover. The foregoing lightning tests are, of course, design tests and not intended for commercial testing. This follows because dismantling every transformer in the routine factory tests to detect possible internal failures is impractical. However, the shield removes the necessity for lightning tests since the impulse distribution becomes the same as that at 60 cycles.

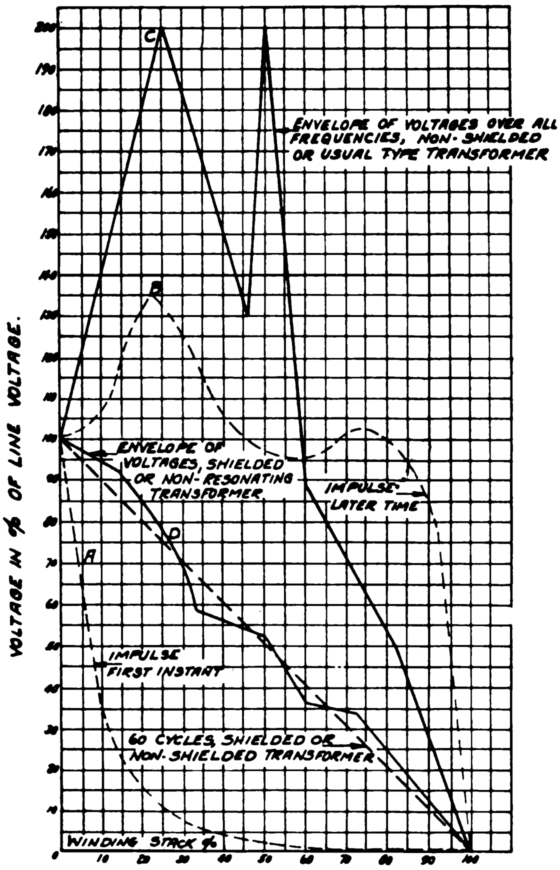
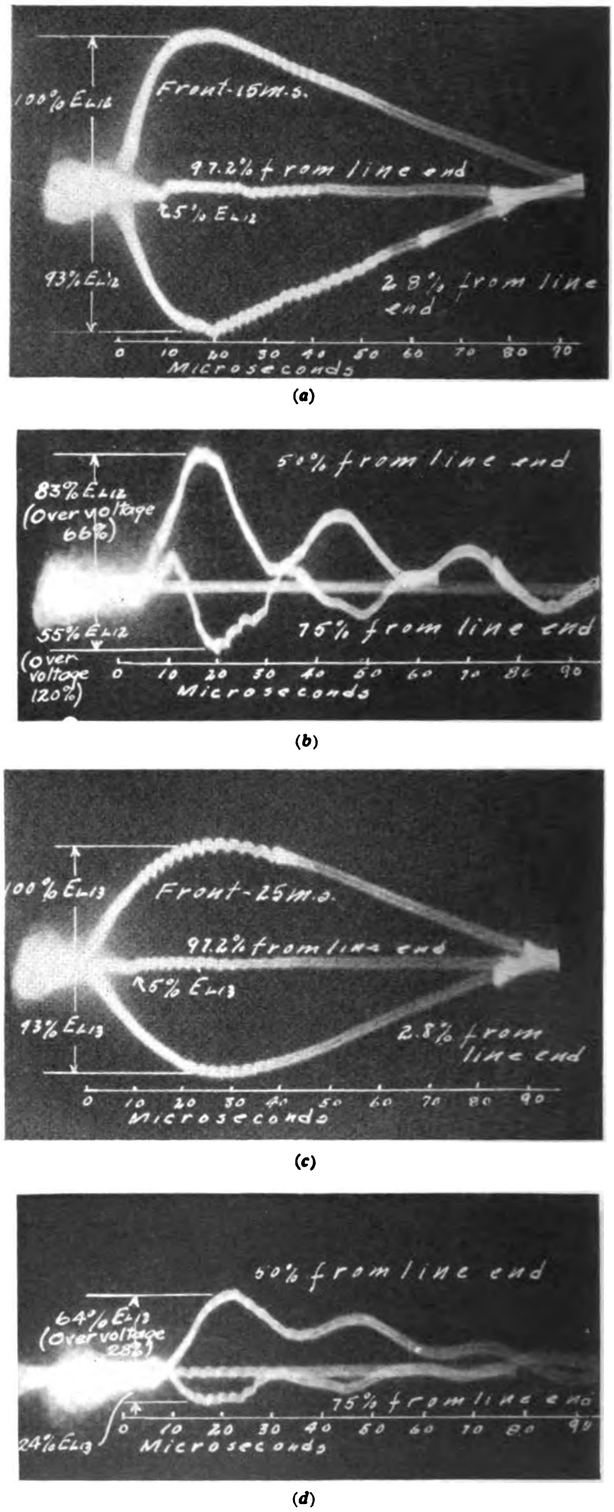


Fig. 23. Envelope of Voltage Distribution of All Frequencies for Shielded and Non-shielded Transformers



(*a*)

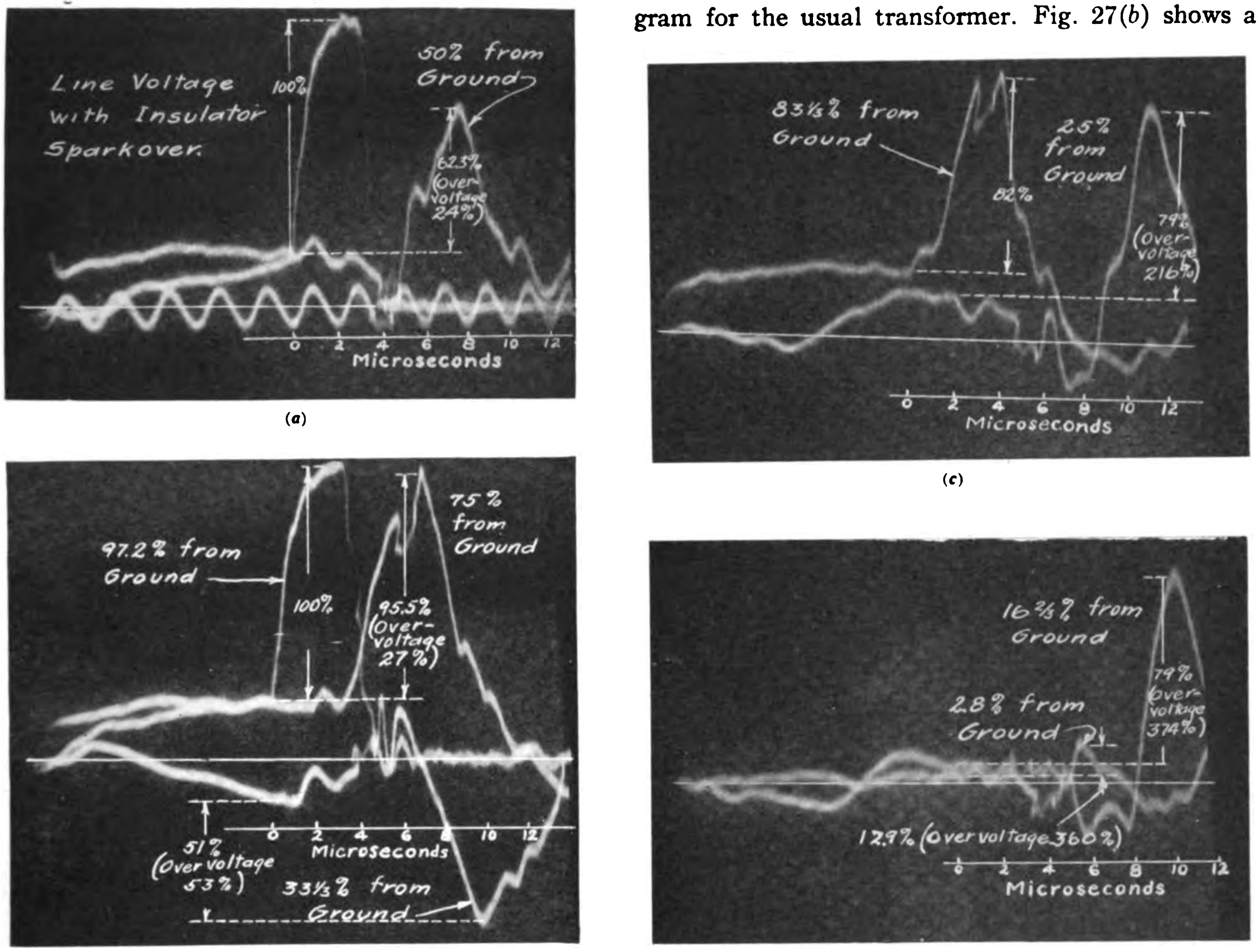
(*b*)

(*c*)

(*d*)

Fig. 24. Impulse Voltage Distribution in an Ordinary Transformer. (Long waves with 15 and 25-microsecond fronts. Note high internal voltages)

The reason for the varying distribution of voltage in a non-shielded transformer is briefly as follows: The initial lightning distribution is determined by the distribution of the capacity in the windings and the 60-cycle or long-duration-voltage distribution by inductance. If the voltage distribution as determined by these factors is not the same, an oscillation results until the distribution corresponds to that of the inductance. The shields make the capacity and inductance distribution correspond. The action of the capacity is instantaneous and there is no oscillation.



(*a*)

(*b*)

(*c*)

(*d*)

Fig. 25. Impulse Voltage Distribution in an Ordinary Transformer. (Chopped wave. Note high internal voltages)

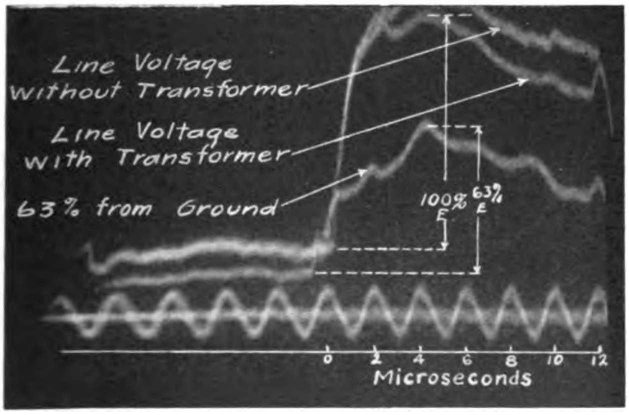
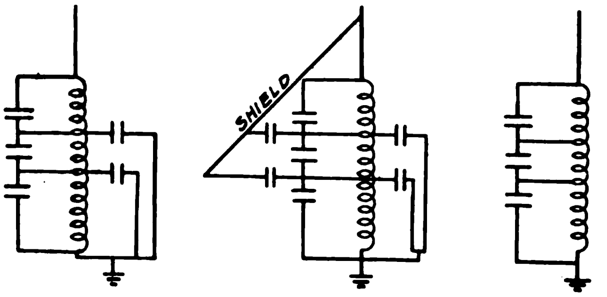


Fig. 26. Impulse Voltage Distribution in a Shielded or Non-resonating Transformer. (Each part of the winding takes its share of the voltage and there is no resonance)

Fig. 27(*a*) shows an approximate equivalent diagram for the usual transformer. Fig. 27(*b*) shows a shield added. Fig. 27(*c*) shows the effect whereby a number of equal capacities to ground are connected to the winding at equal intervals. The cathode-ray oscillograms in Fig. 24(*a*) show a wave with a 15-microsecond front applied to the line end of the transformer. The double wave on this and some of the other records is the result of two measurements being made on the same film. Fig. 24(*b*) shows that 83 per cent of the voltage applied on the line appeared at the middle of the transformer. Fig. 24(*c*) and Fig. 24(*d*) show the results with a 25-microsecond wave. Fig. 25 shows the voltage at various parts of the winding for a wave having a 5-microsecond front chopped by a line insulator, and corresponds to waves measured in practice. The distribution in per cent of the voltage applied at the line end is as follows: 100 per cent voltage at 97.2 per cent of winding from ground; 82 per cent voltage 83.3 per cent from ground; 95.5 per cent voltage 75 per cent from ground; 62.3 per cent voltage 50 per cent from ground; 51 per cent voltage 33.3 per cent from ground; 79 per cent voltage 25 per cent from ground; 79 per cent voltage 16.6 per cent from ground; 12.9 per cent voltage 2.8 per cent from ground. The difference in the shapes of the waves at various parts of the winding, from the applied wave, is evidence of oscillations. Fig. 24 is a very long wave. One record, Fig. 26, is sufficient to show the result when the transformer is shielded. The applied waves are shown with and without the transformer as well as a wave taken at a point in the winding 63 per cent from ground. The voltage at the 63 per cent point is 63 per cent of the applied voltage and the wave is exactly the same as the applied. This shows equal distribution and no oscillation. Fortunately, the shield is mechanically simple and can be incorporated readily in the standard transformers of core-type design.



(a) Usual Transformer (b) Shielded Transformer (c) Effect of Shield

Fig. 27. Diagrammatic Representation of Transformers with Respect to Shielding

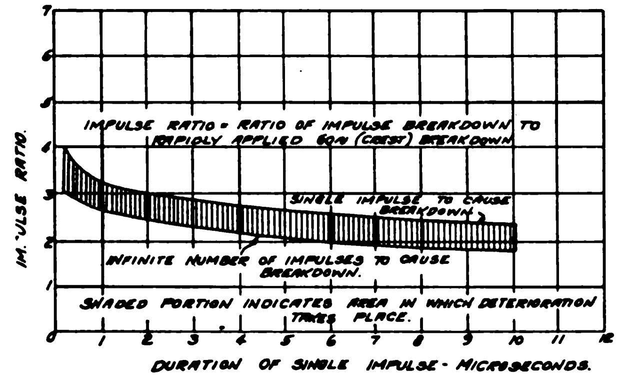


Fig. 28. Impulse Ratio and Cumulative Effect of Impulses. Typical curve: actual values will vary for different kinds of insulations

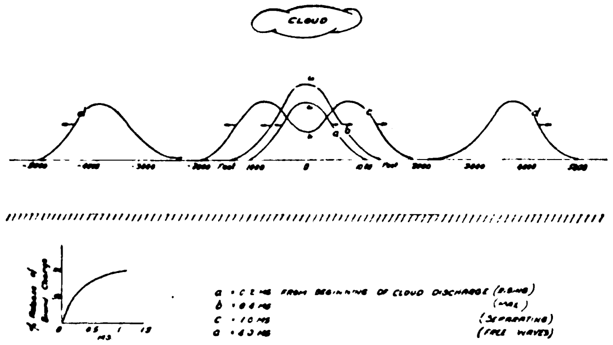


Fig. 29. Formation of Traveling Waves from Peaked Bound Charge (2000 ft.). Released in one microsecond

Insulation

The new lightning generator has made possible extensive research on solid and liquid insulation. The results of some tests are shown in Fig. 28.

Induced Voltages and Direct Strokes on Transmission Lines

In a former paper (1) it was shown that the voltage induced on a transmission line due to lightning was directly proportional to the height of the line, thus:

$$V = gh\alpha.$$

Where V is the induced voltage, g is the gradient in volts per foot, h is the height of the cloud, and α is a factor depending upon the size of the charged cloud over the line and the rate at which the cloud is discharged. If the cloud discharged instantaneously, α would be unity; but, since this is not possible, it must

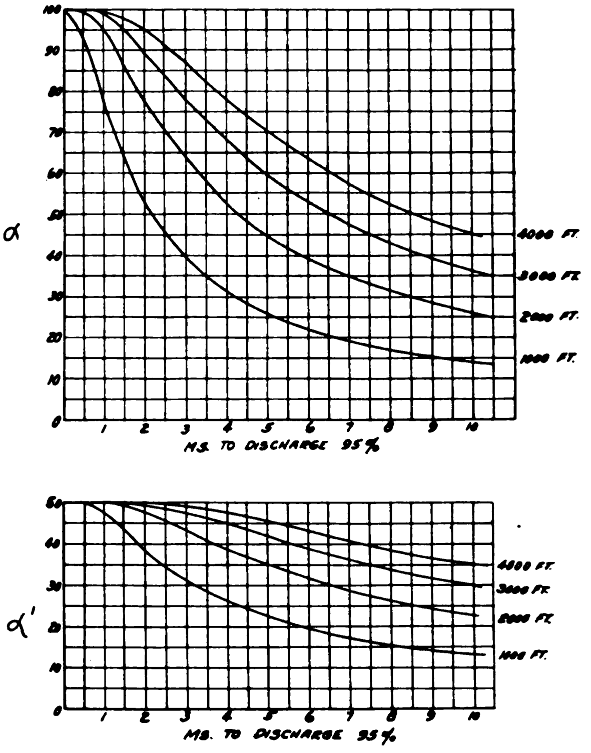


Fig. 30. Values of α and α' for Various Sizes of Clouds and at Various Rates of Discharge on the Assumption of Square Distribution of Charge

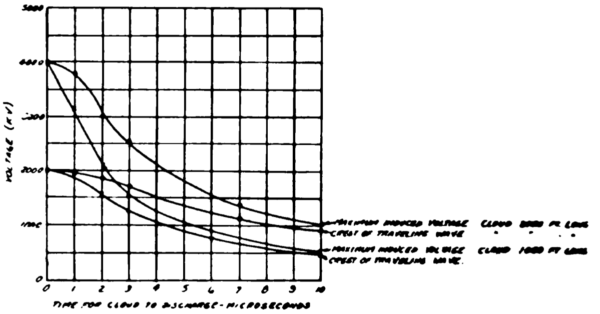


Fig. 31. Maximum Induced Voltages on a Transmission Line Conductor 40 ft. High, for Various Cloud Discharges. (Wave front one to two times length of cloud)

be less than unity. The maximum value of g which occurs directly under the storm center, is equal to the average breakdown strength of the air, and is of the order of 100,000 kv. per ft. ⑴ When the line is some distance from the storm center, the gradient is much less.

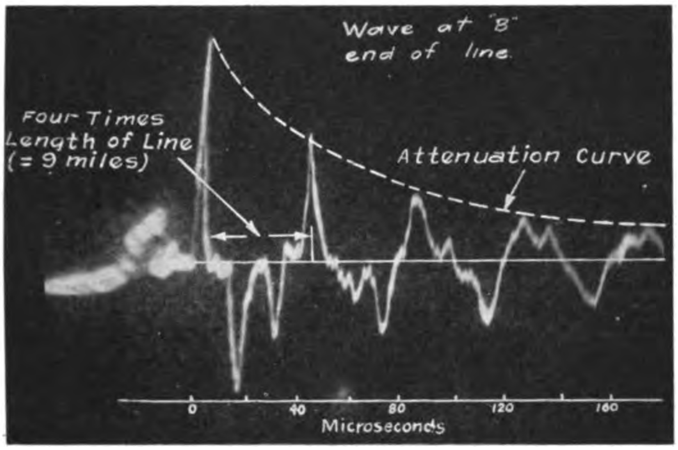
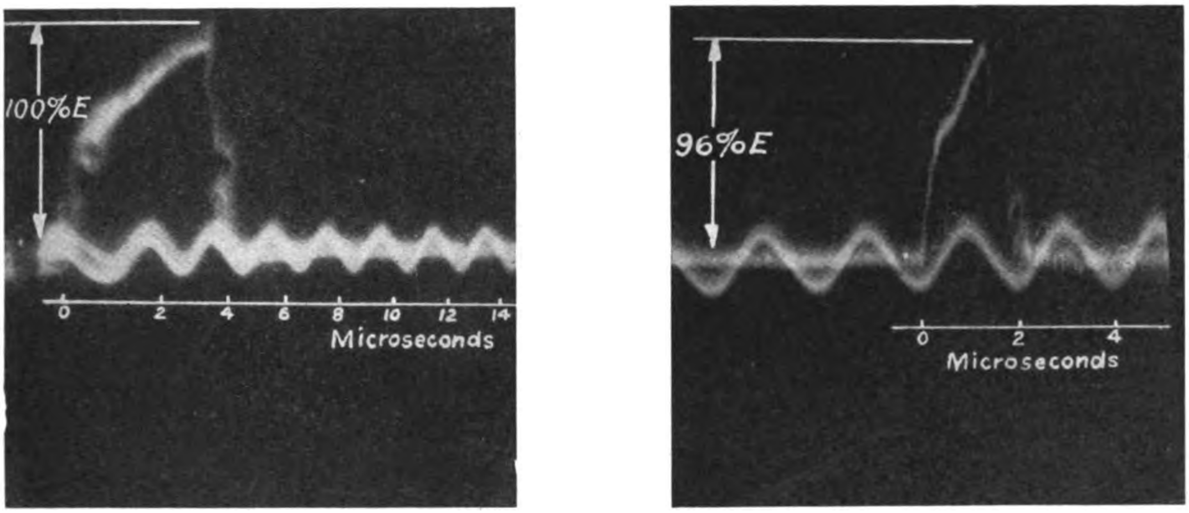


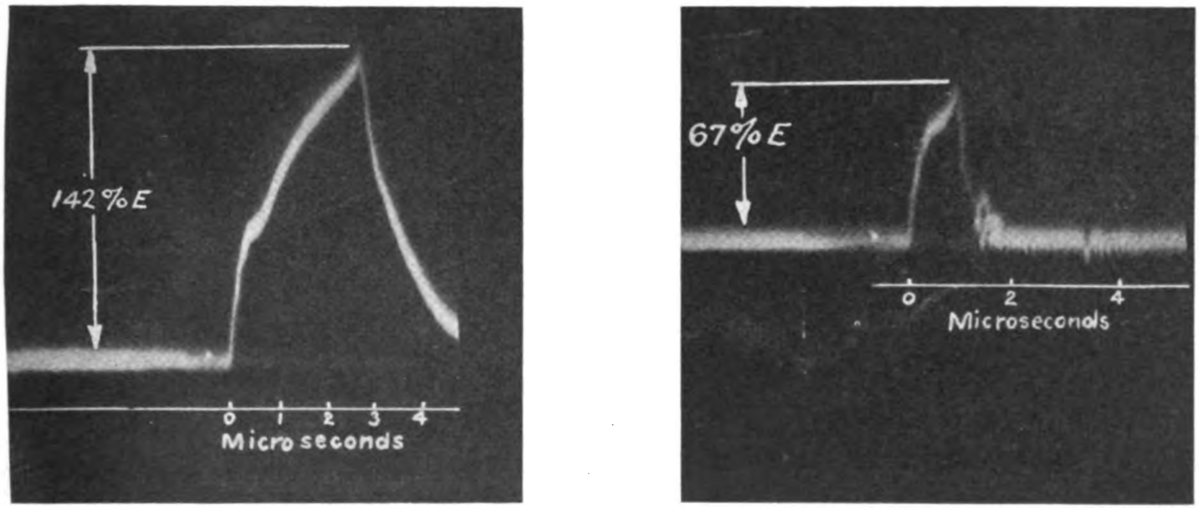
Fig. 32. Voltage Wave Showing Attenuation Suffered in Successive Reflections from Opposite End of Line

The foregoing theoretical expression, which has been checked experimentally on models, is readily understood. The line becomes charged owing to its position in space and would take the potential of the equipotential surface in which it is located, or approximately the voltage gh above ground, if it were not longer than the cloud and there were no leakage. However, because of leakage in the usual line, the extension of the line beyond the field, etc., a charge of the same potential as the cloud moves or leaks away during the relatively slow charging of the cloud, which leaves the line charged opposite to the cloud and at zero potential. The field about the line while the charge is "bound" is the resultant of the linear field and the field on the line. When the cloud discharges, the linear field disappears and the line rapidly rises in voltage due to the charge. That $V = gh$ applies only when the discharge is very rapid or when the line is shorter than the cloud, follows because $V = Q/C$. The bound charge, Q,



(a). Initial Wave at Sending End

(c). Wave Chopped by Gap at Receiving End

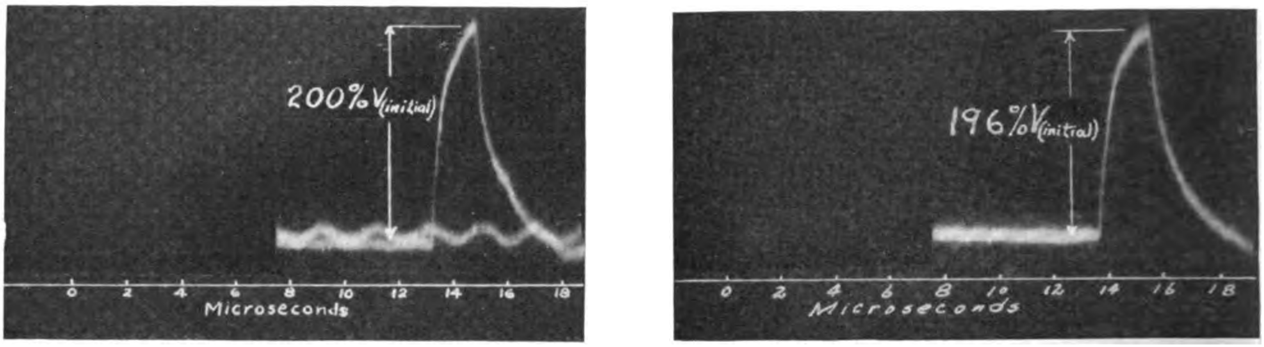


(b). Initial Wave Reflected to Double Value at Open End, After Attenuation to 71 Per Cent

(d). Wave Chopped by Gap at Receiving End

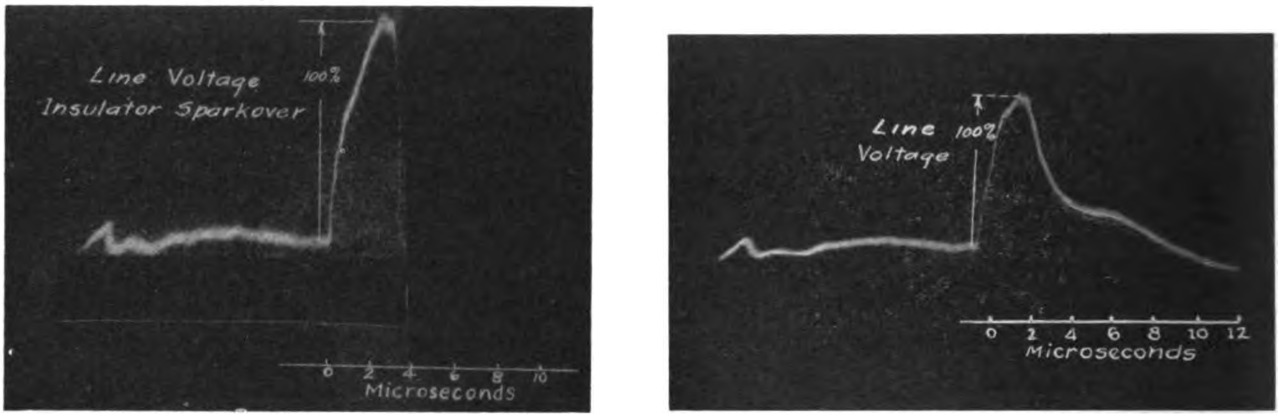
Fig. 33. Cathode-ray Oscillograms of Waves on Transmission Lines

is released at the same rate that the cloud is discharged. If the cloud discharges slowly, Q which travels at approximately 1000 ft. per microsecond, is spread over a considerable length of line and the capacity C becomes very large so that V must be low. The factor α compensates for this. It is interesting to investigate α to determine its probable range in practice to account for induced voltages observed on actual lines.



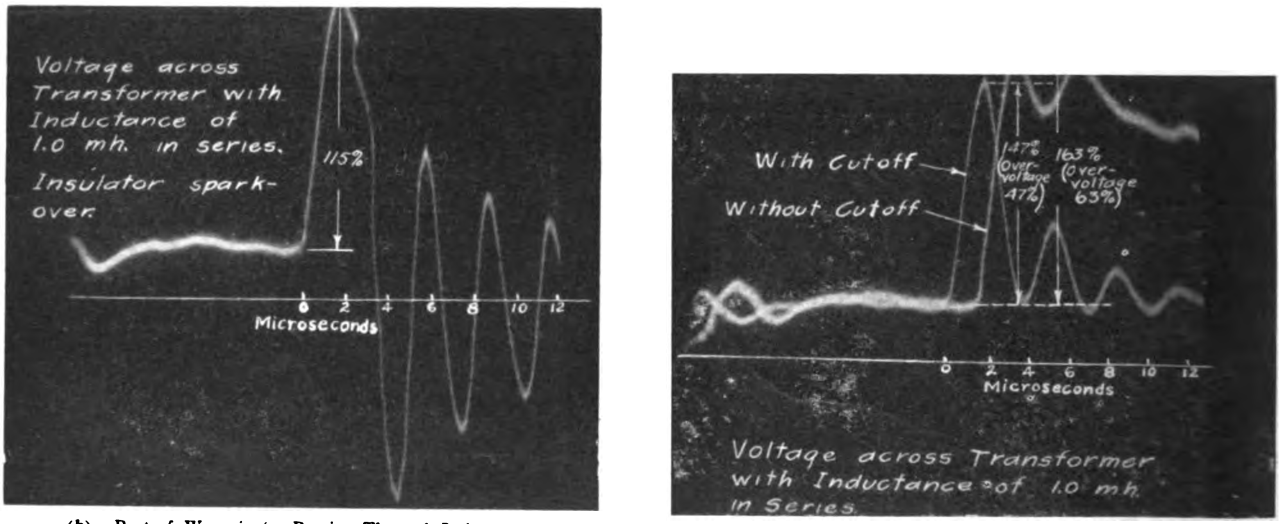
(*a*). Striking an Open End (*b*). Striking a Transformer

Fig. 34. Comparison of Similar Waves Striking an Open End and a Transformer



(*a*). Wave Chopped on Crest by Insulator on Striking Inductance

(*c*). Wave After Striking Inductance



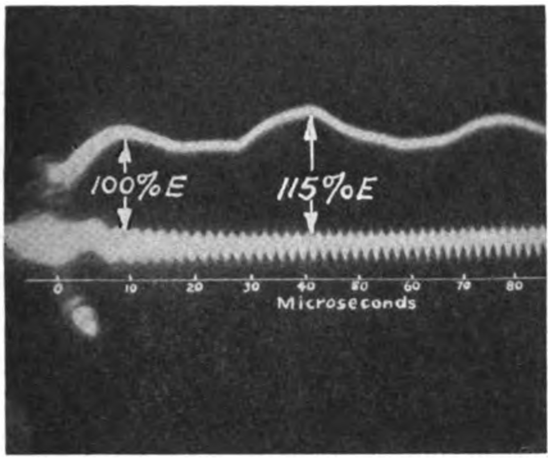
(*b*). Part of Wave in (*a*) Passing Through Inductance and Causing Oscillations at Transformer

(*d*). Voltage Increases and Oscillations Across Transformer by Part of Wave Passing Through Inductance, with and without Being Chopped

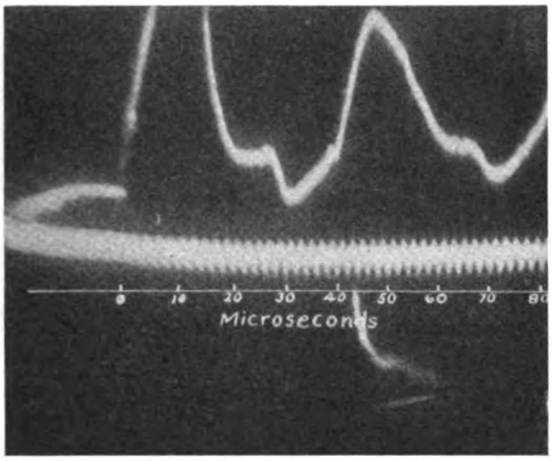
Fig. 35. Effect of Series Inductance on Traveling Waves

The formation of induced voltage on lines is as follows:

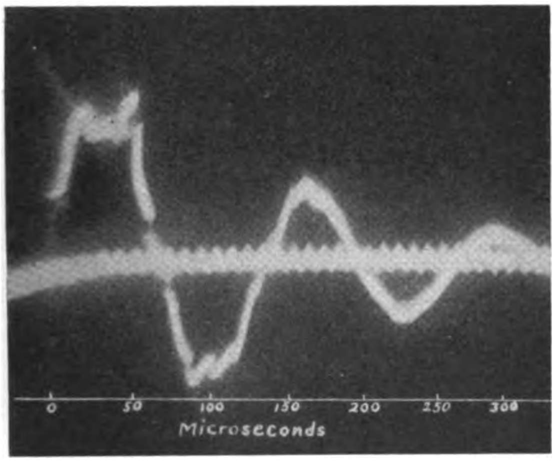
The charging process of the cloud is slow. This permits leakage from line to ground of the charge having the same potential as the cloud. A bound charge opposite in potential to the cloud and varying in intensity with the cloud charge is held on the line. The cloud discharges at a very rapid rate, releasing the charge on the line. The voltage from line to ground increases rapidly to a maximum value. Eventually two equal free traveling waves are formed and propagated in opposite directions with voltages less than maximum. If the discharge were instantaneous, the voltage of the traveling waves would be one-half of maximum value, ***gh***, since half of the energy in the traveling waves is electromagnetic and half electrostatic. The voltage and current waves are in phase in the traveling waves. The formation of a wave on a line is illustrated in Fig. 29. Fig. 30 gives values of α and α' for various sizes of clouds and at various rates of discharge on the assumption of square distribution of charge. The values are lower for a peaked distribution of charge. α is for the maximum voltage; while α' is for the crest of the free traveling wave. For illustration, assume a 2000-ft. cloud discharging in two and four microseconds. The values of α and α' for two microseconds are 0.78 and 0.47 respectively. For a line 40 ft. in height, directly under the storm center, $V=0.78\times100{,}000\times40=3{,}120{,}000$ for the maximum voltage and $V_1=0.47\times100{,}000\times40=1{,}880{,}000$ for the crest of the traveling wave. For a 4-microsecond discharge, $V=2{,}080{,}000$ and $V_1=1{,}420{,}000$. For a 10-microsecond discharge, $V=1{,}040{,}000$ and $V_1=1{,}020{,}000$. For smaller clouds, induced voltages are very much lower. For instance, for a 1000-ft. cloud and a 10-microsecond discharge, $V=560{,}000$ and $V_1=520{,}000$. Fig. 31 gives the induced voltages for cloud discharges up to ten microseconds, when the line is under the storm center or in the maximum field. High induced voltages are thus not possible with slow discharges. When the line is ¼, ½, and 1 mile from the storm center or away from the maximum gradient, the voltages would be approximately 32, 12, and 4 per cent of the foregoing values respectively.



(*a*). Wave at "A" End of Line



(*b*). Wave at "B" End of Line



(*c*). Wave at "A." Needle Gap Sparkover at "B."
7.8-cm. Spacing

Fig. 36. Oscillations Due to Wave Longer Than Line

If the insulator sparkovers do not result at the initial maximum induced voltage, the charge separates into two traveling waves which move over the line at the velocity of light. The front of the waves will probably be of the order of one or two times the length of the cloud. If lightning strikes the line, an insulator sparkover is sure to follow and a short chopped wave of steep front travels over the line. If the voltage is high, there is considerable attenuation due to corona and other losses. The attenuation is well illustrated on the cathode-ray record in Fig. 32 which shows the decrease in voltage of a wave as it is reflected back and forth over a 2¼-mile line with one end grounded.

When the wave reaches the end of a line the well-known reflection to double voltage takes place because the current stops at the open end and all of the energy becomes electrostatic. Fig. 33(*a*) shows a wave starting from its point of origin. On its arrival at the far end it has attenuated to 71 per cent of its initial value. The reflection at the open end causes it to double, when it becomes 142 per cent of its initial value. This is shown in Fig 33(*b*). If a gap is set at the far end with a lightning sparkover voltage of 96 per cent of the initial wave, the voltage at the far end cannot rise above this value but is chopped at 96 per cent of the initial voltage, as shown in Fig. 33(*c*). Fig. 33(*d*) shows the voltage chopped by a gap set at 67 per cent of the initial voltage.

If the end of the line were not open but connected to a transformer and a large bus structure, the voltage would not double up but might actually be reduced below its incoming value. Extra ground wires at the station end, by decreasing the surge impedance, also cause a reduction in voltage and reflection as the wave reaches the bus. With this arrangement it is possible to set a gap (as in Fig. 33(*d*)) at 67 per cent of line insulator sparkover voltage and still have it as secure as the remainder of the line. In this case the bus structure or extra ground wires must hold the voltage to 67 per cent of the incoming wave. A condenser connected from line to ground can be used to keep the voltage down, but it must have sufficient capacity so that the voltage is not above the limit when the condenser is charged by the longest wave.

That an ordinary moderate-size transformer at the end of a line does not behave far differently from an open circuit is shown in Fig. 34. Here the difference in the reflected voltages at a transformer and an open circuit is seen to be only 4 per cent. The effects inside of a transformer are shown in Figs. 24, 25, and 26.

When a wave strikes an inductance coil in series with the line, part is reflected back over the line and part goes through. The latter part may cause very high voltages and oscillations if the end is open or if it is closed by a transformer. The oscillations correspond to the natural period of the inductance and the transformer capacity. If the inductance is shunted by a resistance of the proper value, oscillations may be prevented. The voltage is then usually the same on both sides of the inductance. It is thus seen that series inductance does not give protection against high voltages but may decidedly increase the hazard. If it is used for power-limiting purposes it should be shunted by a suitable resistance. The inductance of a "choke coil" of a few turns is usually too small to have appreciable effect, either good or bad.

Fig. 35(*a*) shows a wave that has been chopped by an insulator and has struck an inductance. Fig. 35(*b*) shows the voltage across a transformer caused by the part of the wave passing through the inductance. The voltage has been increased and there is an oscillation. Fig. 35(*c*) shows also a wave which has struck an inductance. The part passing through the inductance to the transformer in Fig. 35(*d*) increases to 163 per cent of the applied wave and the oscillation is kept to a high value by the tail. When the wave is chopped at the inductance there is an increase in voltage of the part passing through it to 147 per cent but the oscillation is at a lower voltage. Fig. 36(*a*) shows a wave longer than the line being applied to the sending end "A." Fig. 36(*b*) shows the voltage reflections measured at the open far end "B." Fig. 36(*c*) shows the sending end "A" voltage record on the same line with a needle-gap sparkover occurring at the far end "B." The voltage reversal is caused by the current reflection when the far end is short-circuited by the gap sparkover. The sending end in this case was shunted by a condenser thereby causing a lower frequency oscillation.

Magnetic Induction

Voltage may occur on transmission lines by electromagnetic induction. The maximum values would probably result for cloud-to-cloud discharge parallel to the line. Calculations indicate that such voltages would usually be of very moderate value compared with voltages induced electrostatically. However, voltages induced electromagnetically may sometimes be of a noticeable value on low-voltage lines, telephone lines, radio antennae, etc.

(To be continued)

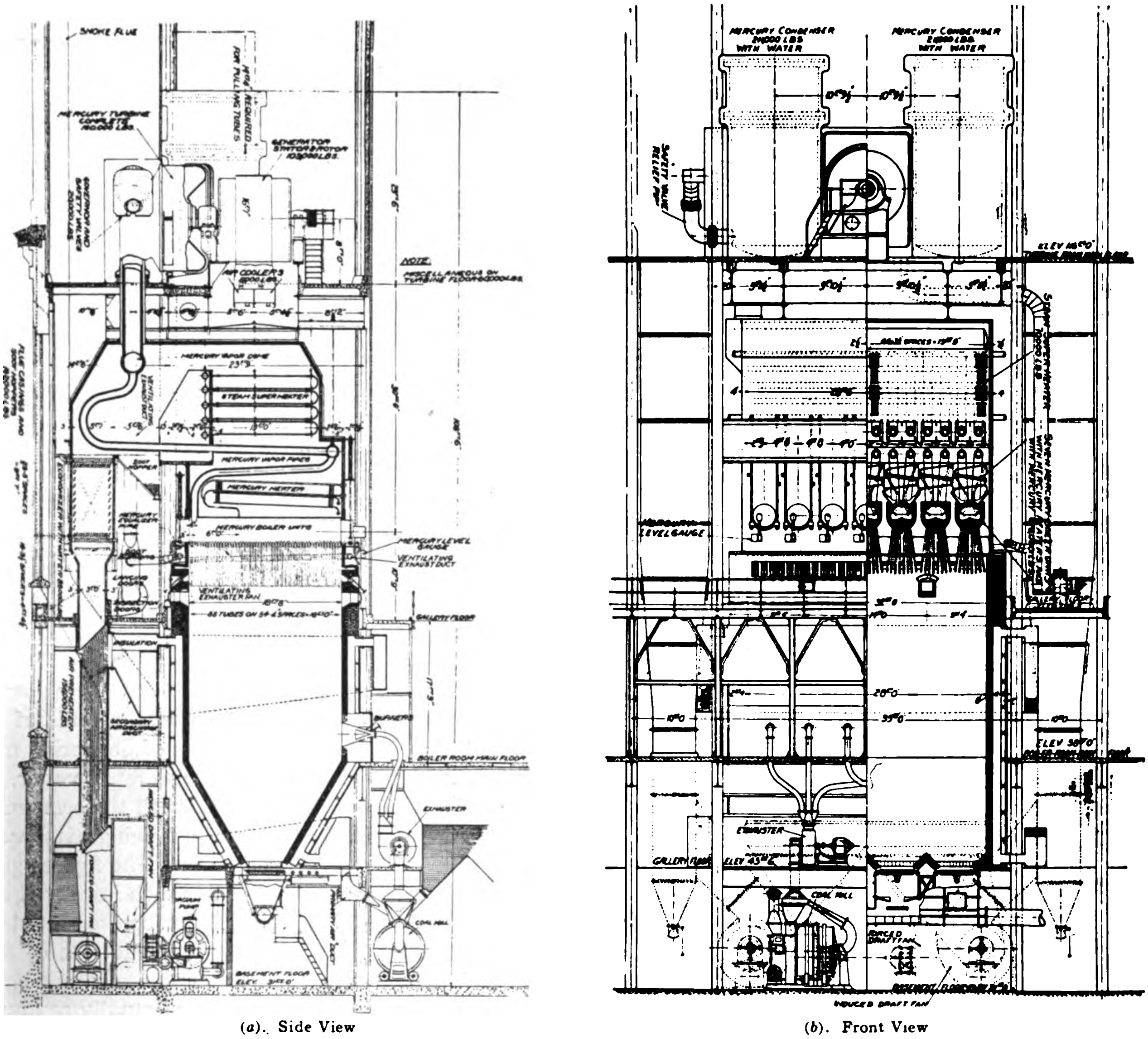
The Emmet Mercury Vapor Process—Results Accomplished

By **W. L. R. EMMET**
Consulting Engineer, General Electric Company

(A paper delivered at the World Engineering Congress in Tokyo, Japan, October 29–November 7, 1929)

As has been stated in previous publications, a large installation for using the Emmet Mercury Vapor process has recently been made in the Meadows Station of the Hartford Electric Light Company. The mercury turbine in this case is rated at 10,000 kw. A previous installation in the Dutch Point Station of that company had a maximum capacity of about 2000 kw.

This larger equipment was completed and put in operation in November, 1928, and was run for about three weeks, much of the time continuously. It then developed a trouble in one of the boiler tubes which showed the necessity of changes in the construction. These changes are now being made. This trouble was due to a mistake in the assembly which arose from a misunderstanding. Experience with the same defect had been encountered before and it is not thought that the matter involves any future danger although, to correct it properly, quite extensive reassembly has been required although the proportions and features of design are not changed. It has also been thought desirable to do some experimenting so that there has been much delay. At the present writing in February, 1929, the rebuilding is still in progress.


MERCURY VAPOR DOME
STEAM SUPERHEATER
MERCURY VAPOR PIPES
MERCURY HEATER
MERCURY BOILER UNITS
BURNERS
BOILER ROOM MAIN FLOOR
GALLERY FLOOR
EXHAUSTER
COAL MILL
BASEMENT FLOOR
LEVEL GAUGE
FORCED DRAFT FAN

(*a*). Side View

(*b*). Front View

Fig. 1. Arrangement of Mercury Vapor Equipment. Output, 10,000 kw. from mercury turbine and 125,000 lb. of steam per hour

This trouble, while very unfortunate as a cause of delay, does not affect the prospects of the success of the process, and since the equipment in all other respects worked beautifully, it may be of interest to give information concerning the results accomplished while this equipment was running, which gave very clear indications of the economies which will be attainable when the process is brought to a commercial state.

The character of the installation in question may be seen from the accompanying drawings, Figs. 1, 2, 3, and 4, which show the arrangement and some parts of the apparatus.

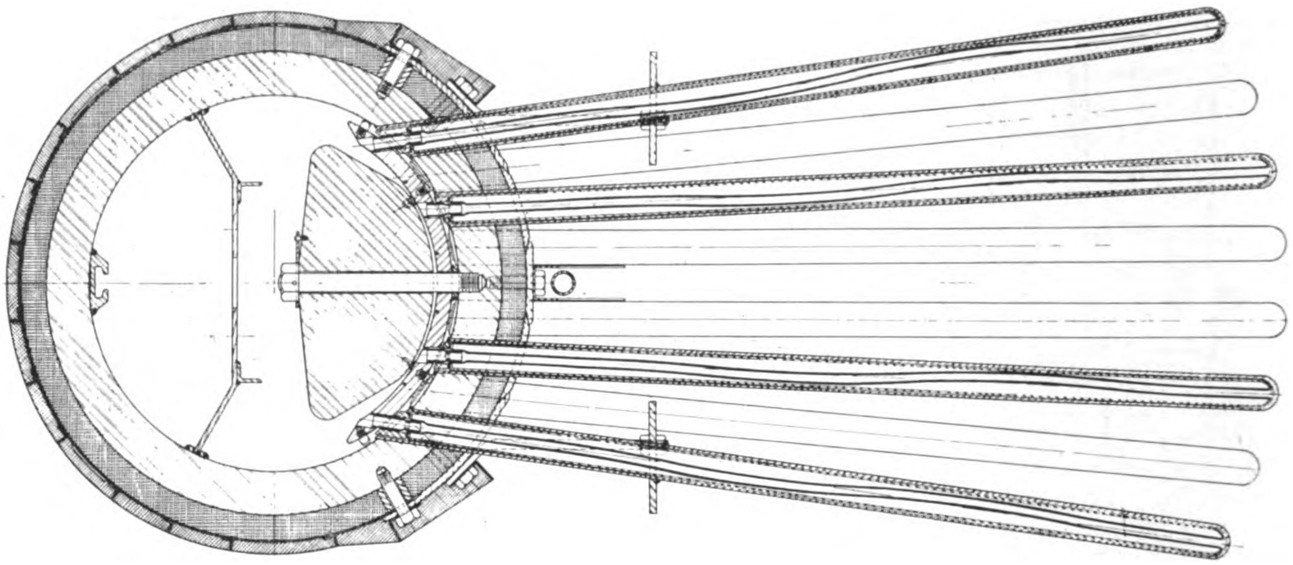


Fig. 2. Cross Section Through Mercury Boiler, 30-in. Drum

In a paper published by the writer in 1927 a statement was given of the results for which this equipment was designed and in the tabulation given below these figures are repeated, and in comparison the results shown by the highest load trial run which was made by the unit while it was in operation:

	As Designed	From Test
Output of mercury turbine	10,000 kw.	10,300
Speed of mercury turbine	720 r.p.m.	720
Steam produced per hour	125,000 lb.	130,000
Steam pressure	350 lb. Gauge	270
Steam temperature	700 deg. F.	810
Mercury vaporized per hour	1,150,000 lb.	....
Temperature mercury vapor	884 deg. F.	880
Pressure vapor at mercury turbine	70 lb. Gauge	68
Vacuum in mercury condenser	28 in.	28.5
Temperature mercury exhaust	458 deg. F.	....
Gas temp. beyond mercury liquid heater	950 deg. F.	1100
Gas. temp. beyond steam superheater	650 deg. F.	720
Gas temp. beyond water economizer	480 deg. F.	....
Gas temp. to stack	280 deg. F.	310
Air temp. entering furnace	390 deg. F.	400
Coal burned per hour	14,500 lb.	15,500
Heat in coal per pound	14,500 B.t.u.	14,300

These figures show that the efficiency of the mercury turbine was somewhat better than we expected, also that the combustion conditions and heat transfers in the surface beyond the mercury boiler were better than expected. The reduction of the gas temperature in the mercury boiler was materially less than was intended, and it is thought that this can be corrected by the introduction of certain baffles which will prevent by-passing and force the heated gases to pass through the heating surface of the mercury boiler in the most effective manner and with a distribution which should be equal instead of very unequal as in the trial.

The correction of these defects would put more heat into the mercury and thus improve the net economy.

Such steam as was made in this trial, if used in the best large apparatus and with the best methods of regenerative feed heating, would produce 14,000 kw. plus all necessary auxiliary power. We should thus have 24,300 kw. from a consumption of 15,500 lb. of 14,300 B.t.u. coal per hour, or 9140 B.t.u. per kw-hr.

In future applications of this process we expect to use the mercury heating surface on the walls of furnaces. This will give us the means of delivering more of the total heat of the fuel to the mercury vapor, will also make it possible to dispense with the economizer and to use more air heating and a much greater application of regenerative feed heating. The figures given above clearly indicate that under such improved conditions a properly designed plant with the best steam apparatus could produce power at the rate of 8900 B.t.u. from fuel per net kw-hr.

This unit, while operating, was actually saving its users about $800 per day in fuel alone. Except in the boiler there was no trouble and no observable deterioration. There was no erosion in the mercury turbine, the furnace showed no deterioration, and the heating surface was easily kept clean.

Plans for the further development of this process include carrying considerable degrees of overload by the simple increase of firing, accompanied by increase of pressure in the mercury vapor. By using a larger generator and a little different arrangement of heating surface a pressure of 100 lb. G. will give over 40 per cent increase of output from the mercury turbine and, owing to the higher temperature limit, the fuel efficiency will be better notwithstanding the greater congestion of the apparatus and of the heating surfaces.

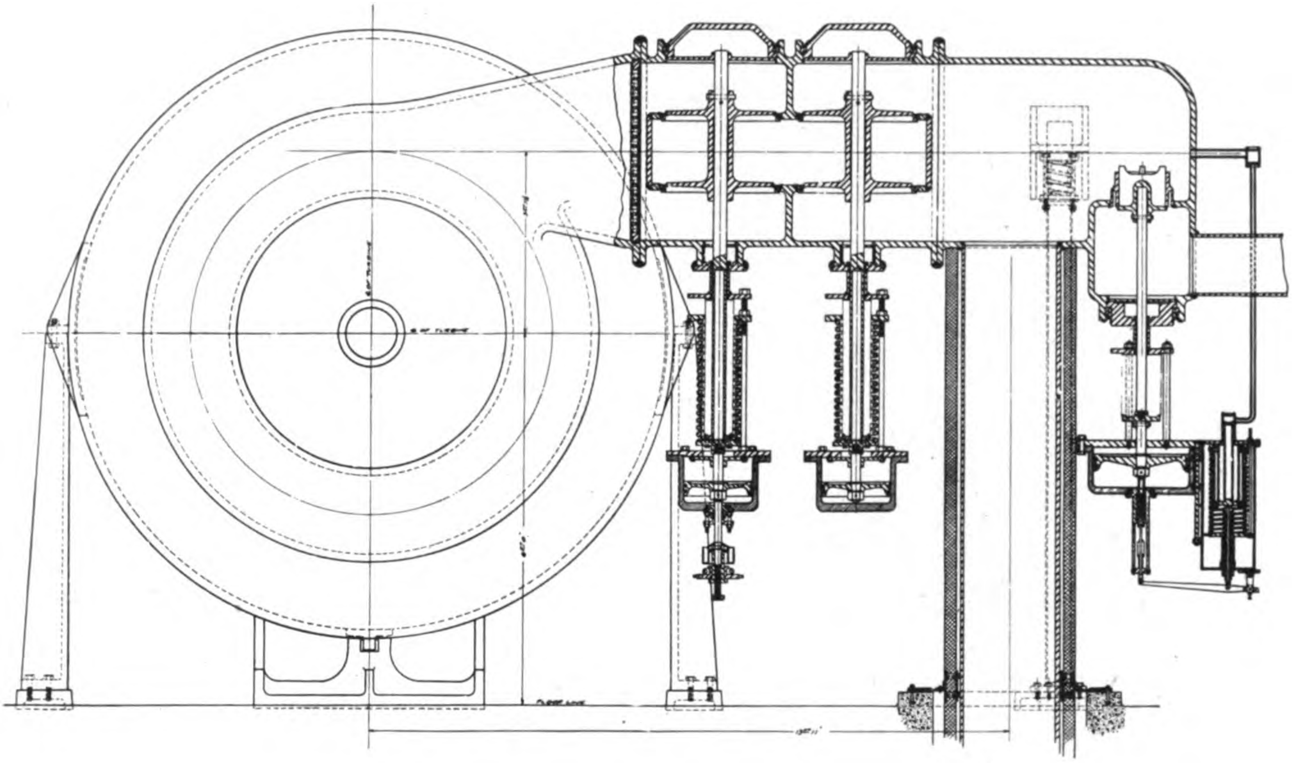


Fig. 3. Valve Mechanism on 10,000-kw. Mercury Turbine

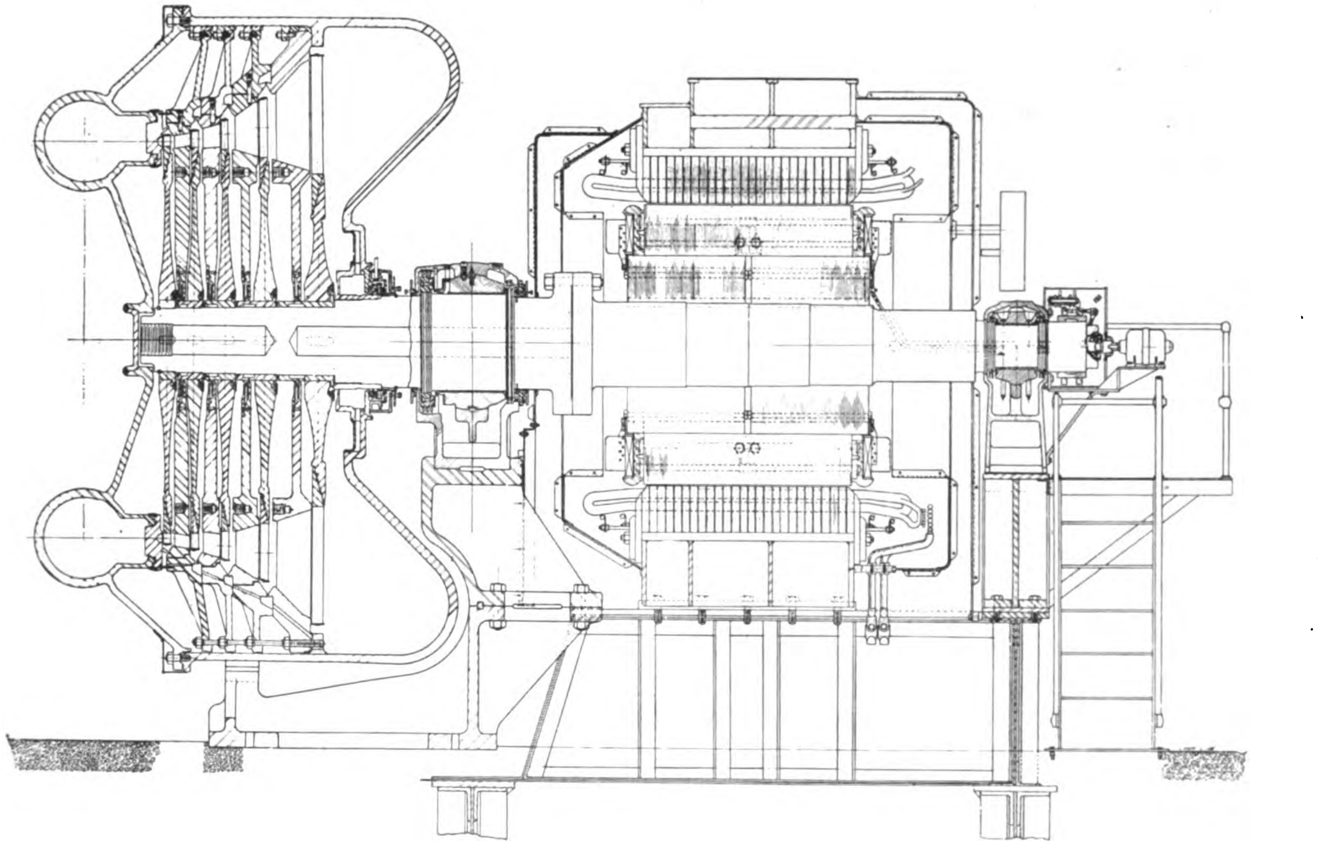


Fig. 4. Cross Section of 10,000-kw. Mercury Turbine and Generator

Structural Steel Welding

By **FRANK P. McKIBBEN**
Consulting Engineer, General Electric Company

(A paper delivered at the World Engineering Congress in Tokyo, Japan, October 29–November 7, 1929)

THAT the art of welding structural steel by the electric arc is progressing rapidly is shown by the recent successful completion of over seventy-five bridges and buildings which have been wholly or partially welded. Included in these are the following examples: (*a*) A steam power plant 144 ft. in height for Hotel Chalfonte, Atlantic City (N. J.), fabricated, erected and welded by the Bethlehem Steel Company; (*b*) a twelve-story addition to Hotel Homestead, Hot Springs (Va.), fabricated, erected, and welded by the American Bridge Company; (*c*) a half-through plate-girder railroad bridge, and a through-truss railroad bridge, at plants of the Westinghouse Electric and Manufacturing Company; (*d*) a large factory building of the mill type and a heavy three-story factory at plants of the General Electric Company; (*e*) plate girders, each carrying 870,000 pounds central load, designed and built by the General Electric Company for use as parts of a thrust bearing in a power plant.

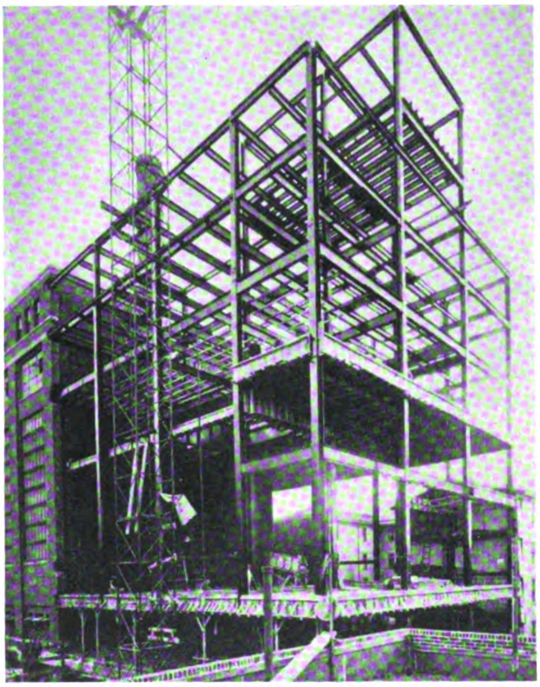


Fig. 1. Steel Power Plant, Hotel Chalfonte, Atlantic City (N. J.). All important field connections welded; secondary field connections bolted. Built by the Bethlehem Steel Company

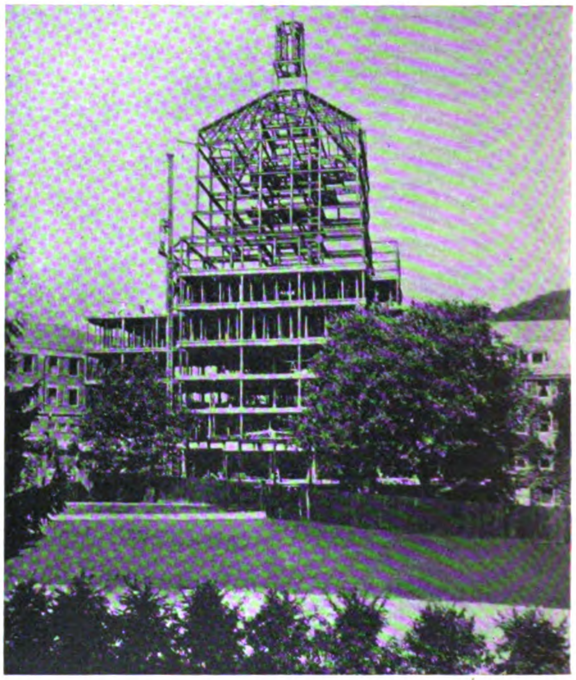


Fig. 2. Twelve-story Welded Addition, Hotel Homestead, Hot Springs (Va.). Built by the American Bridge Company

Welding and Building Codes

Many cities are now revising their building codes to permit welding, but even without a specific clause covering welding, many codes permit the process because they include a clause to the effect that if the commissioner of buildings is satisfied, after proper investigation, that a new material or the new use of an old material is safe, he may authorize its use.

The Uniform Building Code prepared by the Pacific Coast Building Officials Conference, containing a section permitting welding, has been adopted by over fifty-five towns and cities, and the American Welding Society's Committee on Building Codes has drafted a code to cover gas and electric welding, which may well serve as a model for cities to follow.

Tests on Welded Joints

Tests on welds may be classified as determining:

(1). Longitudinal shearing values of fillets.

(2). Transverse shearing value of fillets, involving simultaneous tensile or compressive stresses on some planes within the fillets.

(3). Tensile and compressive strengths of welds in butt joints.

Sufficient test data pertaining to strengths of welded joints are available to enable engineers to produce safe designs, but additional tests are desirable to complete a thorough study of this subject.

Tests are needed to throw more light on longitudinal shearing strength of fillets as influenced by length, size, and number of layers, and while sufficient work has been done to know that these variables do influence the average strength of the fillets, the exact laws of variation have not been established.

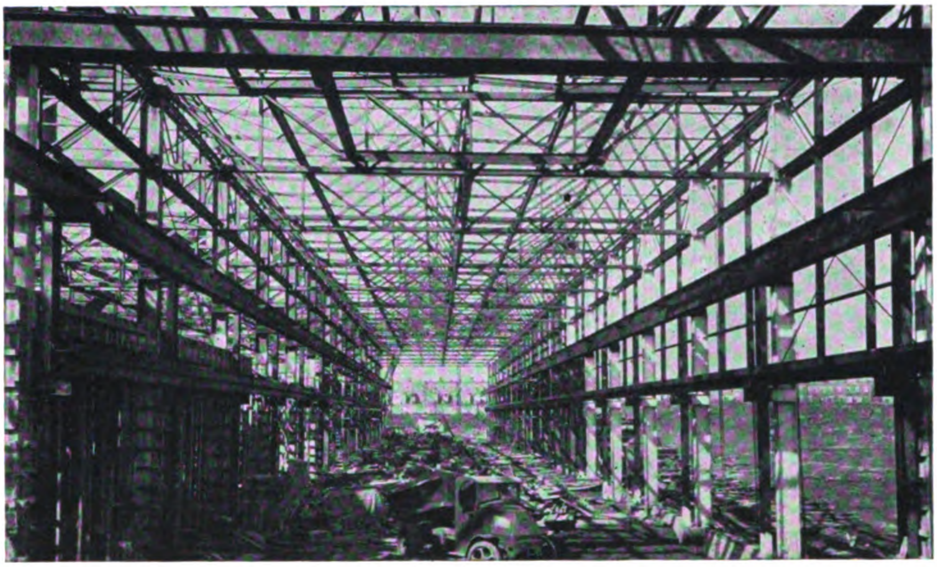


Fig. 3. Welded Factory Building of the General Electric Company at West Philadelphia

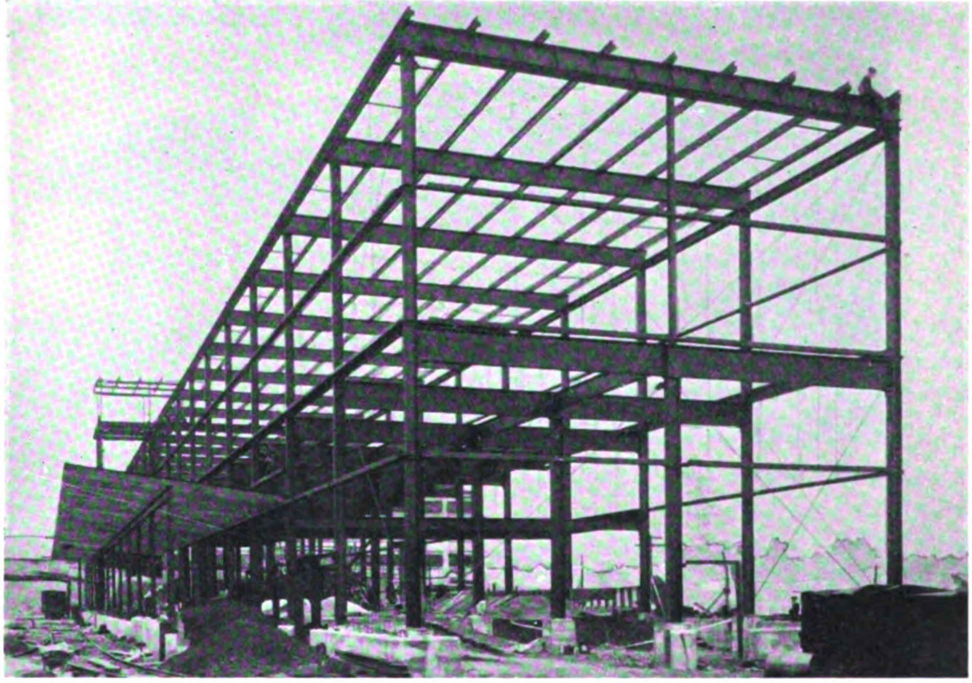


Fig. 4. Welded Factory Building at Pittsfield (Mass.) Works of the General Electric Company

Fillets in transverse shear should give greater strength than in longitudinal shear, because in a properly designed joint the former should have each linear inch of fillet subjected to the same stress; whereas in the latter some inches carry greater stresses than others, just as the end rivets in a row carry greater stresses than does the center rivet.

Welded Plate Girders

Sufficient emphasis has not been laid upon the advantages of welding as compared with riveting in plate girder construction. In a welded girder consisting of a vertical web with one or more plates in each flange, four factors operate to reduce the weight of steel as compared with the weight of riveted girders performing identical functions. These are: Increase in the effective depth, hence greater moment of inertia of cross-section for a given weight of steel; general use of gross areas instead of net for tension flanges of welded girders because of the absence of holes; the use of flat bars for web stiffeners instead of angles, thus eliminating the ineffective angle leg against the web; and the absence of loose fillers.

The savings in weight resulting from these factors are very considerable; for example, welded and riveted girders of 40-ft. spans carrying 4000 lb. per ft. on each span and designed for the usual building unit stresses weigh 5467 lb. and 6455 lb. respectively, a saving of 988 lb., or 15.2 per cent of the riveted girder. (See girders No. 6 and No. 2, respectively, in Fig. 7.) With the use of automatic welding machines, this large saving in weight should likewise result in a considerable cost reduction.

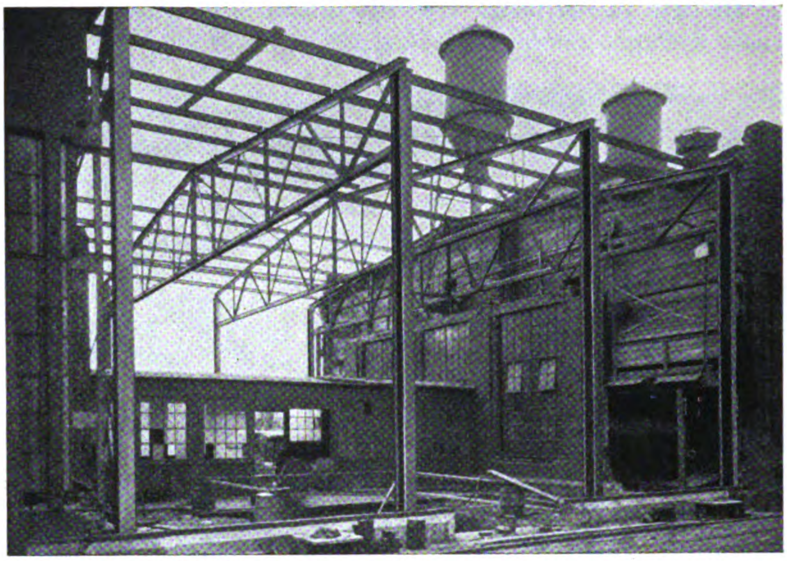


Fig. 5. Welded Trusses in Factory Building of the General Electric Company at Bridgeport (Conn.)

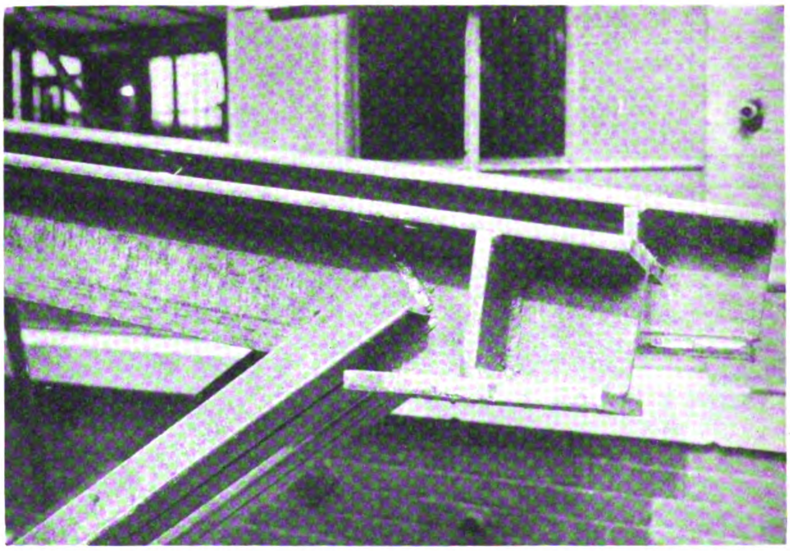


Fig. 6. End Bearing of Welded Roof Trusses, Bridgeport (Conn.) Works of the General Electric Company

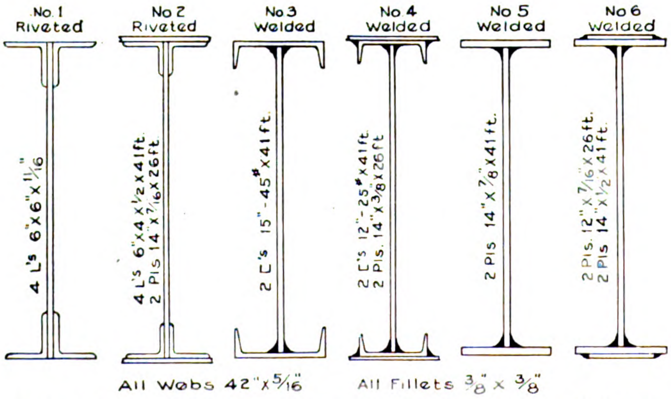

No. 1 Riveted
No 2 Riveted
No 3 Welded
No. 4 Welded
No 5 Welded
No 6 Welded
4 L's 6"X6"X11/16"
4 L's 6"X4X1/2X41ft.
2 Pls 14"X7/16X26ft
2 C's 15"-45#X41ft.
2 C's 12"-25#X41ft.
2 Pls. 14"X3/8X26ft
2 Pls 14"X7/8X41ft.
2 Pls. 12"X7/16X26ft.
2 Pls 14"X1/2X41ft.
All Webs 42"X5/16"
All Fillets 3/8" X 3/8"

Fig. 7. Center Sections of Two Riveted and Four Welded Plate Girders as Designed to Support 4000 lb. Per Linear Foot; Span 40 ft. Welded girder No. 6 weighs 5467 lb.; riveted girder No. 2 weighs 6455 lb.

Qualification of Welders

Before being allowed to weld steel members in an important building, welders should be tested to show their ability to do the kind of work required. These qualification tests should be performed under the supervision of the engineer in charge of the structural steel, who should require the contactor for the steel to show that his welders are qualified to perform the work properly.

These tests should cover welds in horizontal, vertical, and overhead positions; fillets deposited along the offset edges of two plates which upon cooling and breaking apart should show good penetration into the base metals, and freedom from gas pockets, slag inclusions, and highly colored spots. If the welder's ability is still in question, he should weld some sample butt welds and some longitudinal shear welds which upon testing in tension should show satisfactory tensile and shearing values.

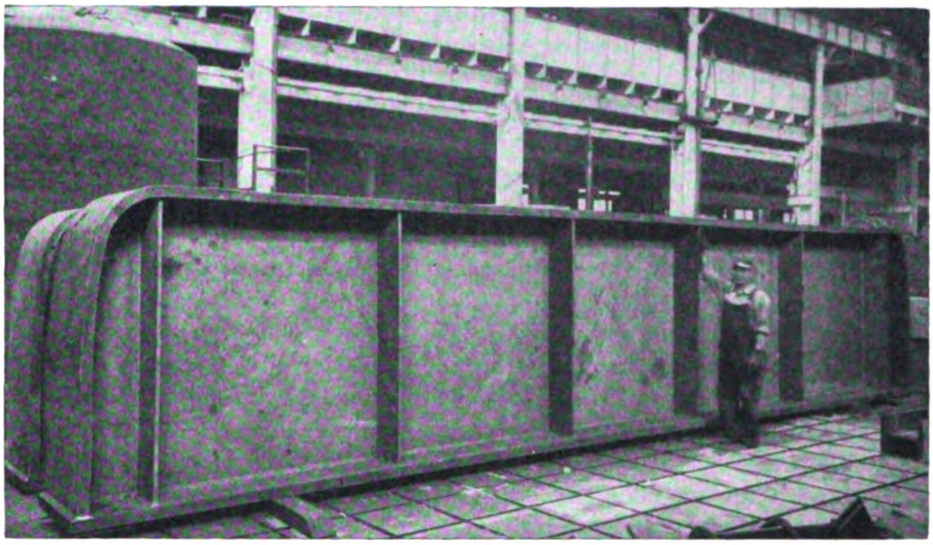


Fig. 8. Welded Plate Girders for Upper Bearing Bracket for a 19,000-kv-a. Waterwheel Generator. Built by the General Electric Company

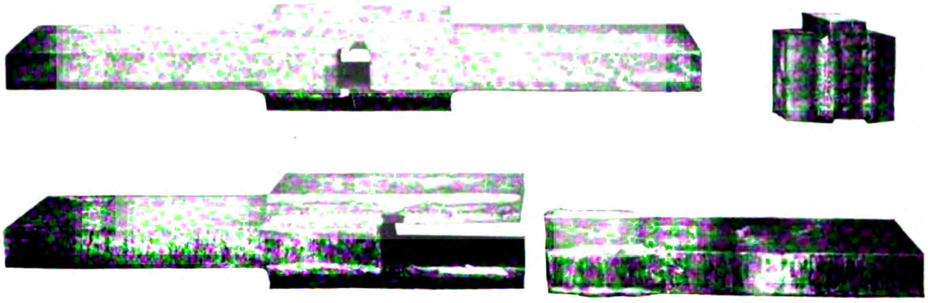


Fig. 9. Welded Specimens Tested to Determine Longitudinal Shearing Strength of ⅜-in. Triangular Fillets. Average breaking strength is 13,400 lb. per linear inch

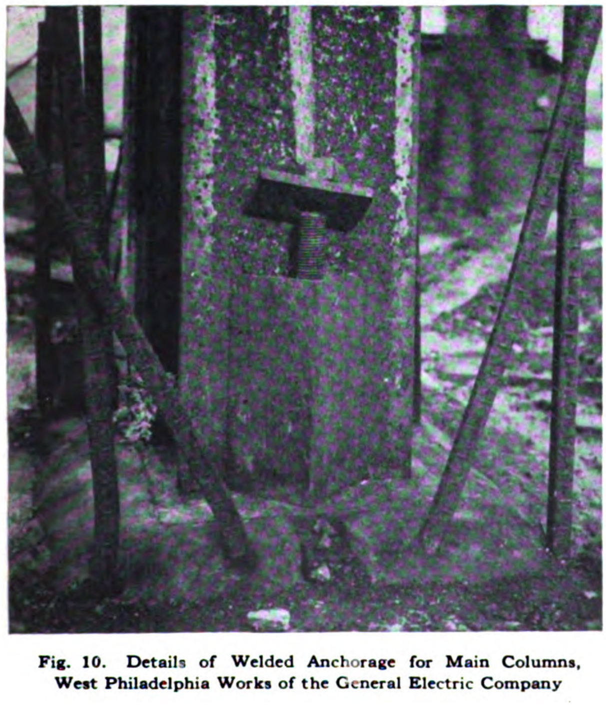


Fig. 10. Details of Welded Anchorage for Main Columns, West Philadelphia Works of the General Electric Company

Inspection of Shop and Field Welding

A capable inspector can tell by visual inspection enough about a weld to classify it as good or poor; and inspection has progressed to the point where structural engineers familiar with the subject have ample confidence in welded joints. The inspector should observe the ammeter to ascertain whether the welder is using the proper current values; should know the chemical composition of the welding wire; and should observe by sound and sight whether the arc is short as it should be, or long as it should not be; whether the edges of fillets are sharp and feather-like, or rounded, the former indicating good penetration; whether the fillet and crater are free from gas holes, as they should be; and whether the crater is of proper depth below the surface of the steel.

Some Phases of Ship Propulsion as Influenced by Modern Power Plant Engineering

The Status of Steam Plants as Producers of Driving Power—Possibilities of Securing Economies When Applied to Ships—Economies Arising from Typical Installations—Comparison of Various Types of Drive—Diesel-engine Propulsion—Typical Performance—Advantages and Handicaps

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(A paper delivered at the World Power Conference in Tokyo, Japan, October 29–November 7, 1929)

MODERN power plant engineering, in the past 25 years, has shown marked improvements in the generation and distribution of power. Twenty-five years ago many of the good plants in the United States required 2.5 lb. of coal to generate one kw-hr. The thermal efficiency was approximately 12.5 per cent. Today there are several large plants generating a kw-hr. on less than one pound of coal, which is equivalent to a thermal efficiency of approximately 25 per cent. Experimental plant tests have recently been made with improved conditions which indicate a further increase up to a thermal efficiency of something over 30 per cent.

The improvements in the larger power stations have been accomplished by utilizing improved steam generation, more efficient units operating over an extended available energy range, recovery of heat by systems of feed water and air heating, decreasing stack gas temperatures, and improvements in the auxiliary apparatus.

The Diesel engine has also played an important part in improving the thermal efficiency of power generation and it is therefore proposed to present in this article the possibilities of the future improvements of ships' propulsion plant along the two main lines of steam and the Diesel engine.

STEAM

The Scotch marine boiler has proved itself throughout many years, but recently the advent of higher pressures and temperatures has led to the perfection of the marine water-tube boiler. However, a relatively small percentage of ships are so equipped and hence this should be one item for future improvement of the world's shipping.

The majority of Scotch boilers certainly are working at not over 250 lb. gauge and 500 deg. F. (260 deg. C.) total temperature. There is in operation at this time at least one ship with water-tube boilers making use of 550 lb. gauge and 750 deg. F. (398 deg. C.) total temperature, and several others using from 250 to 340 lb. gauge and a total temperature from 600 deg. F. (316 deg. C.) to 700 deg. F. (371 deg. C.). The effect of these increases in pressures and temperatures on the plant economy will be considered later. It is mentioned at this point simply to indicate the trend in boiler design.

In combination with the boiler there have been developments and improvements in superheaters, feed water heating, air preheaters, economizers, burners, forced and induced draft arrangements, and condensing equipment which have resulted in marked economies in land plants. Some of these have been applied to various marine installations but there has not been the concerted and combined effort to take advantage of these that there has been in large central stations. Therefore, these features seem to offer possibilities for the future in the marine field.

The foregoing amount to saying that true economy lies in proper coördination of the parts of the entire plant based on modern practice and knowledge of heat conservation and balance. The average ship offers a most fertile field for improvements in this direction.

In the matter of fuel, at present, there appear to be four possible lines of advance in improved economy:

(1). The use of instrumentalities for observing and setting conditions of combustion such as CO_2 content, stack temperatures, and firing.
(2). An increase in the use of oil and possible further gains in burning it.
(3). Replacement of hand firing of coal by stokers.
(4). Use of pulverized coal.

Few ships are properly equipped to determine the factors listed in item (1). In central stations these have proved to be of major importance in achieving in operation what the design of the plant has contemplated. Starting with a determination that the fuel measures up to a specific heat content, and following through the cycle, it is found that maintaining the conditions of combustion and firing are items of operation which are of prime importance; and most ships certainly are not operated on this basis today.

The economical gains which can be made by using oil fuel in place of coal depend to a great extent upon the trade routes and other operating conditions of the vessel; hence broad statements cannot be made; but the situation surrounding each ship must be investigated.

Early installations of stokers did not prove to be suitable for marine service, a circumstance which acted to somewhat retard their further adoption.

However, in some recent installations this experience has been reversed. Quoting from Mr. J. Johnson, Superintending Engineer, Canadian Pacific Steamships, Ltd., London: "On trial, boiler efficiencies of 82 per cent and 75 per cent were obtained with the stoker and hand firing respectively . . . . . . It will be observed from a study of the foregoing table that when the consumptions are corrected to a uniform basis of 13,500 B.t.u.'s the mechanically-fired installations show a higher average efficiency of 9 per cent. The difference has been as low as 5 per cent and as high as 10 per cent on individual voyages. The vessels with the mechanical stokers have registered about ¼ to ½ knot higher average speed."

In a ship operating on the Great Lakes in the United States, similar results were obtained with stokers giving a boiler efficiency of approximately 83 per cent and resulting in a reduction in the fire room force of six men which represents a reduction of 68 per cent of the force required for hand firing.

Some very large installations using pulverized coal have been made on land, and the general attitude of the central station industry in the United States is a sympathetic one; however, it is considered inadvisable to make broad claims at the present time.

Only a few installations have been made on ships and these may be called experimental. Especially is this true of the S. S. *Mercer* in view of the fact that Scotch boilers were adapted to this type of fuel with provision for also burning oil. This, therefore, may offer quite a field for future improvements in certain classes of vessels.

A considerable showing has been made on a moderate number of steamships by the use of electric auxiliaries. With Diesel-engine propulsion the use of electric auxiliaries received a great impetus and confidence was established in them; so that there should be no hesitation on the part of the marine fraternity in accepting their use.

As an indication of what may be accomplished along this line data are quoted from a paper(1) comparing two turbine-electric-driven coast-guard cutters, the *Modoc* and the *Pontchartrain*. In the former, all the usual auxiliaries with the exception of the streeing gear are steam-driven, while in the latter the only steam auxiliaries ordinarily used at sea are the boiler feed pumps; in the latter the steam conditions also have been somewhat improved. Therefore, these vessels offer an excellent comparison on this item of electric auxilaries. Captain Newman states that on the *Modoc* approximately 32 per cent of all steam produced went to auxiliaries, under the full-power condition. In the case of the *Pontchartrain*, the corresponding figure is approximately 14 per cent. On the Great Lakes cargo ship referred to previously, the steering gear and a small amount of stoker machinery are the only steam auxiliaries. On this vessel the steam required for all other auxiliaries, which are taken from the main electric propulsion unit, is less than 10 per cent of the total steam used. These figures speak for themselves.

As stated, in both of the cases cited the auxiliary power is taken from the main turbine and for the most part directly from the main propulsion generator by the use of alternating-current motors. However, where direct-current auxiliaries are considered essential, this result, with a slight reduction in the saving, may be accomplished by the use of a motor-generator set. This has been used on a second Great Lakes cargo boat.

A study of the S. S. *Virginia*, where the electric auxiliaries are taken from separate turbine-generator sets having a water rate of 14.6 lb. per kw-hr. under actual sea conditions, shows that a saving of approximately two per cent would be had if the auxiliaries were taken from the main unit through a motor-generator set. This ship, because of electric cooking, heating, and cargo refrigeration, has a rather unusually large auxiliary load and, therefore, the saving made by using the motor-generator set is less than would be the case were smaller, and hence less efficient, auxiliary turbines used in the ordinary way.

A scheme for improving economy and speed of existing reciprocating-engine-driven ships has been introduced in Germany. This is known as the Bauer-Wach system. It consists of a turbine using exhaust steam from the engine and connected to the propeller through reduction gearing. A modification of this system is being built in England using electric transmission between turbine and propeller. In the latter case the expected saving in fuel at the same speed of the ship is between 20 and 25 per cent. It is the writers' understanding that in existing installations of the geared type an increase in speed requiring an increase in power in the same order of magnitude as the case here cited has been secured with the same rate of fuel consumption. Considering the recent change in economical speed of the ordinary cargo boat, this arrangement may well prove of considerable importance for the future rehabilitation of existing ships.

Turning now to the specific savings which may be looked for by the use of these various modern means, a brief survey of land central stations may be of value.

The practice in general use about 1920-22 showed a consumtpion of approximately 1.85 lb. of coal per kw-hr. at the switchboard on a basis of 13,500 B.t.u. per lb. of fuel. Modern plants operating from 400 lb. to 1200 lb. gauge, 725 deg. F. (385 deg. C.) to 750 deg. F. (398 deg. C.) total temperature, 29 in. vacuum, and with varying amounts of reheat show a consumption from 0.97 to 0.85 lb. of coal per kw-hr. on the same fuel basis.

The future as indicated by expectation may bring about the following results: for the mercury-steam process, 0.695 to 0.665 lb. of coal per kw-hr. corresponding to various mercury pressures and stages. The gas turbine exponents also indicate about the same expectations of that type of prime mover.

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(1)"A Central Power Station Goes to Sea," by Commander Q. B. Newman, U. S. C. G.

From operating data covering 12 ships, four equipped with reciprocating engines and the remainder with geared turbines of gross tonnage from approximately 5,000 to 10,000 there is deduced a fuel oil consumption ranging from 1.11 to 1.48 lb. per s.hp-hr. with an average of 1.253 lb. Correcting this to a kw-hr. basis and also for 18,500-B.t.u. oil as against 13,500-B.t.u. coal, we arrive at 2.3 lb. of coal per kw-hr. at the shaft. These vessels were built from 1916 to 1922 and hence belong to the same period as the central stations with which we have compared them. Those built before 1920 have lowered the average fuel consumption, and therefore, have not influenced the comparison adversely for the ships. This comparison indicates what might be accomplished by putting modern central station practice into the marine field, as the present status of the ships compare unfavorably even with the 1920-22 central station results.

That at least some of this gain is obtainable from actual operation at sea may be seen by examining data available on some modern turbine-electric-driven vessels. Captain Roger Williams in his paper, "Description and Trials of the S. S. *California*," gives data which show a consumption of 0.77 lb. of oil per s.hp-hr. for all purposes over the entire voyage from New York to San Francisco and return. This is equivalent to 1.41 lb. per kw-hr. at the propeller shaft on a basis of 13,500-B.t.u. coal. On this ship, as stated of her sister ship, the S. S. *Virginia*, there is an unusual auxiliary load in electric cooking, heating, and cargo refrigeration. The average steam conditions involved were 250 lb. gauge at the throttle, 507 deg. F. (264 deg. C.) total temperature, and 28.5-in. vacuum. These were practically the design conditions.

The power plant of the S. S. *Virginia* is the same as that of the *California* except that the design pressure is 270 lb. gauge at the throttle and the total temperature is 614 deg. F. (323 deg. C.). On its second voyage the *Virginia* averaged between pilot stations 0.74 lb. of oil per s.hp-hr. for all purposes. This represents a saving of four per cent over the *California* on the same route.

These vessels have conditions which still depart considerably from the most modern central station practice. This applies to steam pressures, total temperatures, and the lack of air heaters and some of the instrumentalities for maintaining operating conditions. They do have two stages of feed water heating. As an indication of what improvements can be expected with higher steam conditions on the *Virginia*, calculations have been made for 350 lb. gauge, 700 deg. F. (371 deg. C.) total temperature and 550 lb. gauge, 725 deg. F. (385 deg. C.) total temperature. These indicate a saving of approximately five per cent for the first conditions and eight per cent for the second, not taking into account the possible improvements in boiler efficiency due to perheaters, etc. As stated previously, a further saving of two per cent is indicated if the power for the auxiliaries were taken from the main unit through a motor-generator set.

Mr. J. Johnson (previously quoted) gives for the S. S. *Duchess of Bedford*, a geared-turbine ship having approximately the same s.hp. as the *Virginia* with turbine-electric, a figure of 7.3 lb. of steam per s.hp-hr. for propulsion only. The steam conditions are 340 lb. gauge, 680 deg. F. (360 deg. C.) total temperature and 29-in. vacuum. These correspond very closely to those assumed for the first set of improved *Virginia* conditions given above except for the vacuum. Taking the water rate corresponding to the five per cent gain mentioned and correcting it for 29 in. as against 28.5 in. vacuum, we arrive at a figure of 7.26 lb. per s.hp-hr. for the electric propulsion equipment only.

Actual operating data on the P & O vessel *Viceroy of India*, equipped with turbine electric drive, have not as yet been published; but according to *The Shipbuilder*: "The fuel consumption trial under full-load conditions was carried out at a scheduled speed of 18¼ knots, the power developed being 13,322 s.hp. at 103.5 mean r.p.m. With a vacuum of 28.93 in., the consumption of the turbines only worked out at 0.581 lb. per s.hp-hr. which is less than 0.6 lb. when corrected for standard vacuum and feed conditions." This indicates that the selection of this type of drive with 375 lb. gauge, 700 deg. F. (371 deg. C.) total temperature, and 28.5 in. vacuum is to be justified.

Expressing these results on turbine-electric ships in thermal efficiency, the value of 18.6 per cent may well be claimed for the entire plant including a large passenger auxiliary load.

The point has been made that data published for the U. S. S. *Saratoga* show as great a fuel consumption as 1.308 lb. of fuel per s.hp-hr. for propulsion only; and the inference has been drawn that this indicates that with turbine electric drive the efficiency does not increase with the horsepower as expected. In examining these data the following facts should be kept in mind: a warship does not present the most advantageous conditions because of great restriction in space and weight; economy is emphasized more at the cruising than at higher speeds; the turbines were designed in 1919; the steam conditions at the time these data were obtained were 258 lb. gauge, 495 deg. F. (257 deg. C.) total temperature, and a vacuum of 26.85 in.

In adopting higher steam conditions, the ship operator is practically faced with using a form of turbine drive. The alternatives lie in the method of connecting the turbine to the propeller shaft, *viz.*:

direct connection, mechanical or hydraulic gearing, and electric transmission. The prohibitive size, weight, and low efficiency of the direct-connected turbine has practically eliminated this alternative. For some years the technical publications have been well supplied with the arguments for gearing and electric transmission, and it is, therefore, not the writers' intention to go into this matter in great detail. However, it should be pointed out that as steam pressure, temperature, and shaft horsepower increase, the difficulties of the geared turbine with its reversing unit also materially increase and enter an undeveloped field, whereas, with the electric transmission, land equipment is well in advance of marine, both in range and efficiency; further, the inefficient reversing unit is entirely eliminated.

One of the points requiring very careful consideration in using high-temperature steam, especially in the larger units, is the deteriorating effect of foreign matter in the boiler water; in fact, due to this condition the term "boiler water" is rapidly being abandoned in favor of some more suitable one, such as "steaming fluid." With the geared turbine the temperature changes in the condenser are considerably greater than with electric drive and may well result in more difficulty in keeping the system tight and, hence, free from sea water. Starting with a pressure of 300 lb. gauge and 700 deg. F. (371 deg. C.), the reversing element of a geared unit, owing to its low efficiency and absorption of energy stored in the ship, may theoretically reach a temperature of 1200 deg. F. (648 deg. C.) at the instant of reversal. Actually, the temperature is probably nearer 900 deg. F. (483 deg. C.), because of radiation, etc., dropping to 250 deg. F. (121 deg. C.) when the wheel is going astern at approximately 80 per cent revolutions, and with full steam flow. This latter temperature would be maintained during the remainder of the reversing operation. With turbine-electric drive, under the same steam conditions, the maximum exhaust temperature occurs at no-load and reaches a value of approximately 250 deg. F. (121 deg. C.) with only a fraction of full-load steam flow.

In addition to the elimination of a separate reversing unit with its attendant difficulties, electric drive makes available full power for reversal as contrasted with the usual geared-turbine practice of two-thirds.

From the point of view of economical operation, the electric drive offers the distinct advantage of a simple means of fully loading a part of the propulsion plant for reduced speed conditions. This is particularly important on mail ships such as the *Viceroy of India*, where the schedule calls for full power only when necessary to make up for delays or to meet a special connection. This is accomplished by operating one of the two main turbine-generator units and offers the opportunity of running the plant at a more uniform load-factor than is usually obtainable even in central stations.

Maintenance and depreciation are important items in economical operation. On nine turbine-electric-driven vessels put into commision in the years 1921-24 and in continuous operation up to the present there have been no major repairs to the electrical equipment. By this is meant repairs comparable to replacing gears or pinions in geared turbine installations. To the best of the writers' knowledge there has been but one generator failure on turbine-electric ships. Of this type there have been twenty-three in operation since 1925, sixteen of which were running in 1921 or earlier. There have been motor failures, due principally to inexperience on the part of both designers and operators, leading to overheating and aggravated by salt air conditions. In recent practice, more conservative design factors have been used and, where practical, closed cooling systems have been incorporated using surface air coolers with sea water circulation. In all cases of motor failures the ship's force has been able to make temporary repairs by cutting coils out of the circuit or inverting the motor primary and secondary, thereby reaching port under the ship's own power.

DIESEL ENGINE PROPULSION

The overall efficiency of the Diesel engine plant is without question greater than any modern steam plant in practical operation at this time. However, from the point of view of actual economy expressed in cost of fuel, lubricating oil, and maintenance, its standing is by no means so clearly in advance of the steam plant. In fact, for certain classes of service and trade routes, data are available to support the contention in favor of steam. Contracts have recently been signed by a company operating ships out of Atlantic ports of the United States to Central and South American ports in which the price stipulated for bunker oil is almost exactly one-half that for Diesel oil. Taking the figure of 0.74 lb. of oil per s.hp-hr. for all purposes quoted previously for the S. S. *Virginia*, it will be seen that to equal this performance in the matter of fuel oil cost only, a Diesel plant would have to deliver a s.hp-hr. for all purposes for 0.37 lb. of oil under the conditions which this operator encounters. This is a better economy than the writers have seen claimed for the Diesel.

The company referred to has both turbine-electric and Diesel-electric vessels operating over these trade routes. They are therefore in a position to make favorable comparisons. They report a fuel cost per mile on the Diesel-electric of $1.01 as against $0.83 for the turbine-electric. The first vessel has 2500 s.hp. and the second 3000 s.hp. Even the most radical opponents of electric transmission would hardly claim that these figures would be equalized by the use of direct Diesel drive.

The item of lubricating oil throws quite a weight against the Diesel engine in the analysis of operating costs under these conditions. The same company reports the use of 1200 gal. of lubricating oil per month for the Diesel-electric ship and 47 gal. a month for the turbine-electric. Even at the rather low figure of $0.40 per gallon the Diesel-electric drive is penalized over $460 per month.

A second operating company in the United States, having somewhat different conditions to meet, gives a ratio of 1 to 1.7 for the cost of bunker *vs.* Diesel oil. On this basis a rate per s.hp-hr. for all purposes of 0.425 lb. is needed to equal the *Virginia*. Captain R. D. Gatewood, in his paper "Engines of the U. S. Shipping Board Diesel Conversion Program," gives figures ranging from 0.414 to 0.473 lb. of fuel per b.hp-hr. for shop tests. These fuel rates are for the engines alone, except that in some cases injection and scavenging air compressors were attached. The ratings of the engines vary from 2700 to 3300 b.hp., but it should be noted that the Diesel engine has as good a thermal efficiency in small sizes as large; these figures are quoted for fuel-rate comparisons and not for the purpose of comparing small ships with the *Virginia*, a vessel of 17,000 s.hp. The efficiency of a steam plant, of course, increases with its size.

It is not intended to infer that these data pertain to all Diesel installations or to all trade routes and sizes of vessels. It is appreciated that European countries particularly have many Diesel installations which are showing very satisfactory results, but the price of the two grades of fuel oil are more nearly the same than those quoted in the foregoing instance.

Further, there are conditions under which this type of prime mover has the advantage due to weight and space limitations, when the fuel bunker capacity is considered. In fact, in the U. S. Shipping Board Program described by Captain Gatewood most of the vessels converted ply between the United States and Far Eastern ports, or make what are practically "around the world" cruises. For such long voyages, the space and weight requirements for fuel are very important factors.

An instance in which the analysis of the conditions resulted in the selection of the Diesel engine with electric transmission is the conversion by the U. S. Shipping Board of the vessels *Courageous*, *Defiance*, and *Triumph*. These were built in 1918-19 during war-time activities. They were of 11,773 dead weight tonnage with 2645 s.hp. geared turbine drive and designed for 10-knot speed. Under post-war conditions this speed is not economical; and in studying the problem, model tests indicated that 13 knots with a s.hp. of 4000 could be economically obtained by reducing the propeller speed to 60 r.p.m. and changing the lines at the bow and stern.

Quoting from *Marine Engineering* of January, 1929: "Further it was found that Diesel-electric machinery of 4000 s.hp., designed to drive the modified hulls at a speed of 14 knots, would weigh less and require a less expenditure in hull changes for installation than direct Diesel drive. Due to the improved propeller efficiency possible at the lower propeller speed that could be used with electric drive, it was found that the seagoing propulsive efficiency would be better and the fuel consumption as low, if not lower, than with direct drive."

Trials have been run on all these vessels and they are now on their first voyages since conversion. Data should therefore soon be available as to the practical results achieved, although it will no doubt be difficult to determine what gain in efficiency can be attributed to the low-speed propeller.

A further example of a field in which the Diesel engine may claim advantages over steam is that of low or moderate horsepower. An American company is operating five tankers, ranging in s.hp. from 1800 to 2800, equipped with Diesel-electric drive. It also has one 410-s.hp. tanker and three tugs with 370 s.hp. similarly equipped. According to data received from this company on the 1800–2800-s.hp. class, the fuel consumption for all purposes is within the range quoted from Captain Gatewood's paper for b.hp.; *i.e.*, it is somewhat more than the lowest and considerably below the highest figure given by Captain Gatewood. It should be noted that the sea auxiliary load on these tankers is low and is taken from the main engines. Steam plants of this size would be hard pressed indeed to equal this performance even with a ratio of fuel-oil costs of 2 to 1 in their favor.

One of the gains resulting from the use of electric transmission in tankers and other classes of vessels having a relatively large port load is the use of part of the main plant for this purpose. This avoids the investment in a separate auxiliary plant which must be carried at sea without return.

Certain classes of ships, such as ferries, tugs, and fire boats, have long periods of idleness; and the Diesel plant, therefore, has the distinct advantage of reducing the standby losses. The electric drive with a multiplicity of engine units adds a further gain where the schedule, such as usually arises with ferries, calls for reduction of speed and power during certain periods. This is, of course, accomplished by shutting down some of the units.

While mentioning electric transmission for these special types it may be well to point out that owing to its adjustable gear ratio characteristic, the speed of the propeller can be adjusted to the work at hand, allowing the engines to run at constant speed and power. By "work at hand" is meant, for example, in the case of tugs, different towing conditions, varying from running light to the heaviest tow or docking a vessel. Another example is that of a double-ended ferryboat where independent operation of the two propellers may be had from the same power plant.

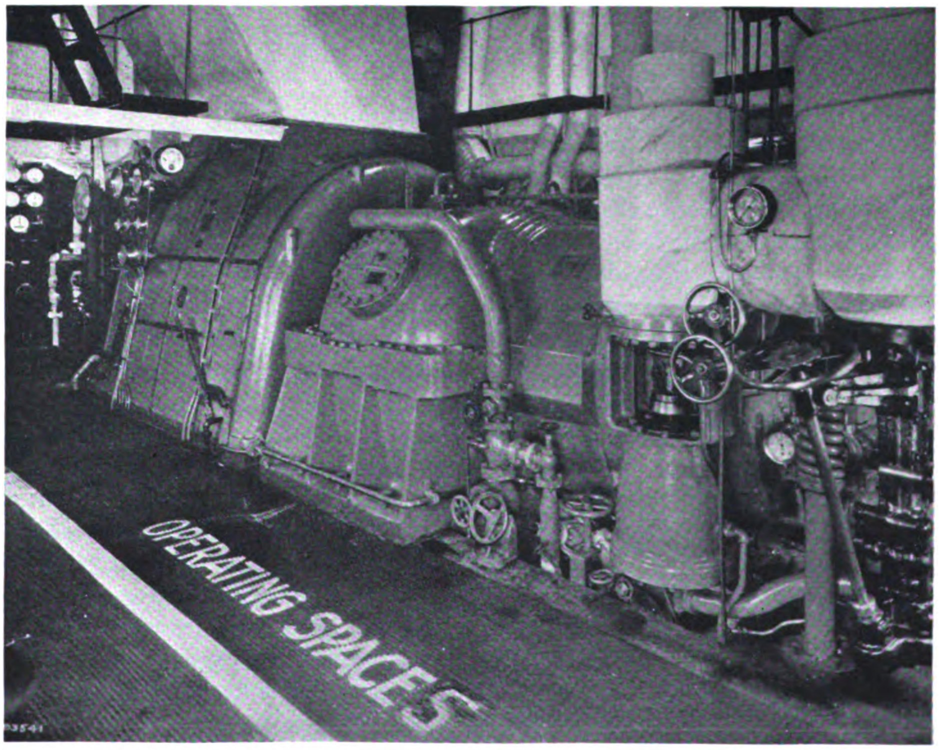
The Diesel engine is at present handicapped by high first cost and weight. The electric transmission should prove to be of assistance in reducing both these items, as the speeds of the engines are increased with improved designs. The electric drive will allow the speed to be increased to a greater degree because of the use of a multiplicity of smaller units and its reduction gear characteristic. In the matter of cost, the electric transmission will permit greater standardization of unit sizes with the accompanying economical manufacturing methods.

No doubt it will occur to some that the addition of the electrical equipment may offset the expected gains in cost and weight. In answer we might say that even with present engine speeds this has in certain cases proved not to be the case, and with increasing speeds the weight and cost of the electrical apparatus is reduced.

A further comment usually made with regard to electric drive is that a loss is encountered in transmission. Theoretically, this loss is present to the extent of 12 to 15 per cent in Diesel-electric direct-current plants of horsepowers installed at present. In actual operation, as covered by the data previously quoted, this loss cannot be discovered when compared with direct Diesel drive. This is apparently due to some of the factors mentioned in favor of electric transmission, such as more uniform load-factor and angular velocity of the propeller, coupled also to the fact that the propeller speed may be selected entirely independent of that of the prime mover.

In closing, let it be said that no pretense is made of having covered in this article all phases of economical operation of ships' power plants; the subject is so extensive and involves so many different factors that each set of conditions must be individually studied. No single paper could serve to properly canvass the entire field even if all the data were available.

The writers here express their appreciation of the coöperation extended by The Atlantic Refining Company of Philadelphia (Pa.); The Bradley Transportation Company of Rogers City (Mich.); the International Mercantile Marine Company of New York; and the British Thomson-Houston Company of Rugby, England, in furnishing some of the data quoted. It is only by such coöperation between the operating and manufacturing companies and through their combined efforts that the improvements here outlined can be accomplished.



A Turbine-generator Unit of a Marine Power Plant

Some Economic Aspects Affecting the Design of Large Power Transformers

Increase in Kv-a. Rating—Growth in System Voltages—Efficiencies—Capitalization of Losses—Increased Complexity of Design—Lightning—Insulation—Reliability

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General Transformer Engineering Dept., Pittsfield Works
General Electric Company

(A paper delivered at the World Power Conference in Tokyo, Japan, October 29–November 7, 1929)

A REMARKABLE change in the design requirements of large high-voltage transformers has taken place during the past five or ten years. This has been brought about by a number of factors, such as the increase in the kv-a. capacity of power plants and substations, the extension of transmission to higher voltages and greater power concentration, the interconnection of systems, and the development of what can be properly described as high-voltage distribution networks.

Increase in Kv-a. Rating

The economies resulting from the use of large units are obvious, and a gradual growth in the maximum kv-a. rating is to be expected as the size of stations increases and the art advances. This growth for self-cooled and water-cooled transformers is shown in Fig. 1. In Fig. 2 is shown an autotransformer having an output capacity of 83,333 kv-a., which is probably the maximum ever concentrated in a single unit.

In addition to the increase in size of units, the relative number of very large units also is increasing.

It is desirable that transformers be shipped assembled and, if possible, filled with oil. Occasionally it is necessary to ship them removed from their tanks, but only in special cases is it economical or desirable to dismantle transformers for shipment to the extent of tearing down the cores and removing the windings. Aside from the limitations of shipping assembled units, there does not appear to be any engineering reasons why very much larger units may not be built.

Growth in System Voltages

The early efforts toward high-voltage transmission began about 1892; and in 36 years the growth in voltage has progressed at the fairly uniform rate of 6600 volts per year, as shown in Fig. 3. Whether this growth in voltage will continue is largely a question of economics. The transformer insulation problems have been worked out well in advance of commercial requirements, and when higher voltages are required the transformer designer will be ready to furnish the transformers.

Efficiencies

Large transformers are inherently so much more efficient than any other piece of power apparatus that for many years operators did not press the manufacturers to reduce the losses in large transformers since they usually had an efficiency well above 98 per cent. First cost was the primary consideration and it could hardly be expected that manufacturers would make any serious effort to design for reduced losses unless this effort should also show a reduction in cost. This statement does not apply to small distribution transformers which usually operate at a very poor load-factor. A great effort has always been made to keep down the losses in distribution transformers, particularly the core loss.

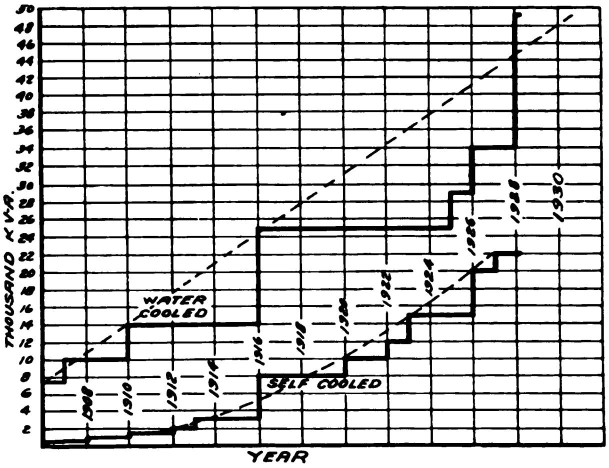


Fig. 1. Growth in the Capacity of Transformer Units

In recent years there has been a decided tendency for operators to consider the cost of supplying losses and a real incentive has been given to the designers of large transformers to obtain high efficiencies. Fig. 4 shows the maximum efficiencies at full load obtained on large transformers of 66,000 volts and above. In 1928, the transformer designers began paring from the last half of one per cent of loss.

Fig. 5 shows the interior of a transformer having a full-load efficiency of over 99½ per cent.

Reductions in losses have been accomplished principally by the following means:

(1). Improvements in the laminated steel used in the cores, and in the construction of the cores, to reduce extraneous loss.

(2). Better insulating materials resulting in improved space-factor.

(3). Refinements in design, particularly toward the reduction of eddy-current losses in the copper and adjacent material in the path of the leakage flux.

(4). Reductions in the flux densities in the cores and the current densities in the copper. These reductions have been accomplished by adding active material.

Unless some totally unforeseen development occurs, it does not appear that improvements in maximum efficiencies to be expected during the next five years will be comparable to the improvements obtained during the past five years. A more general study of "capitalized losses" by operators, however, should result in appreciably better average efficiencies for all large transformers.

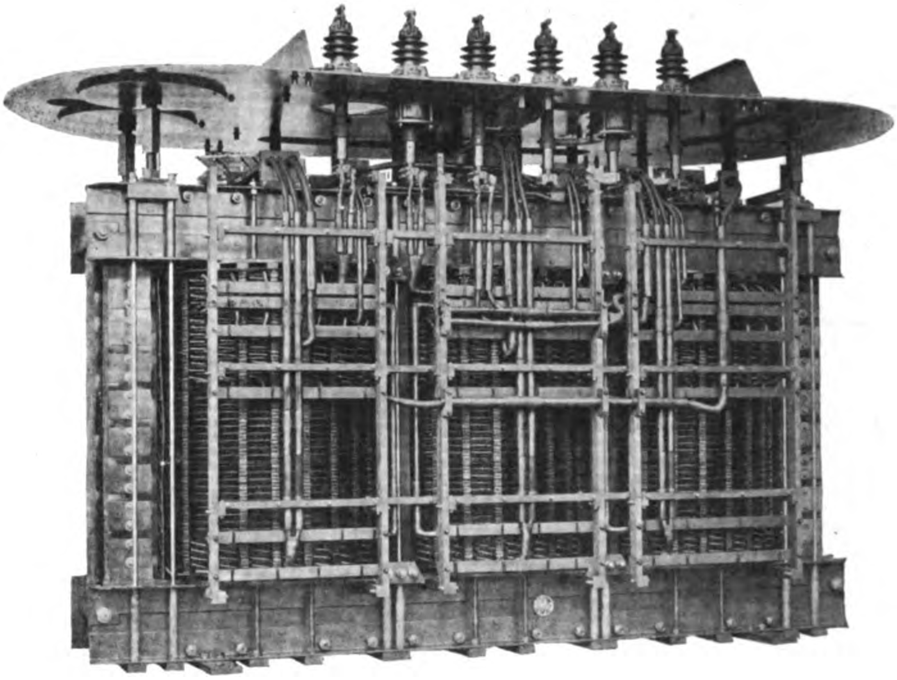


Fig. 2. Autotransformer Rated: Water-cooled, Three-phase, 25 Cycles, 83,333 Kv-a., 24,500Y-12,000Y Volts

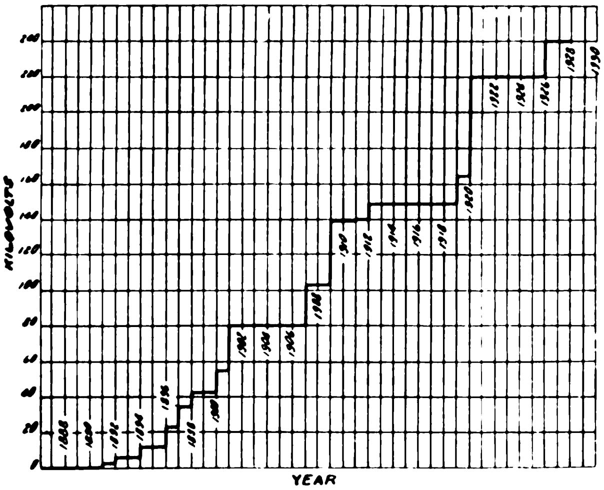


Fig. 3. Maximum Transmission Potentials; 1886 to 1928

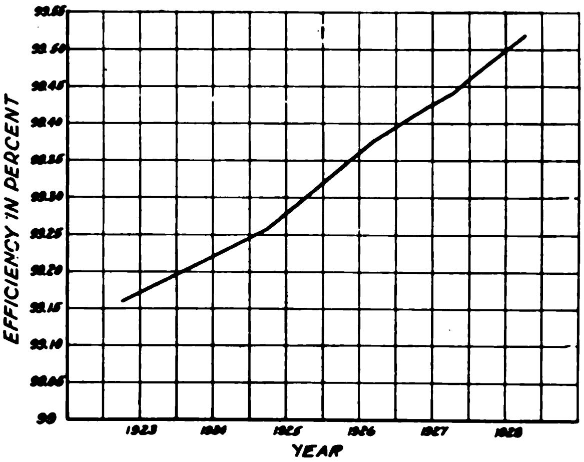


Fig. 4. Highest Efficiencies Obtained from Transformers of 66,000 Volts and Above

Capitalization of Losses

A few years ago, little attention was paid to the efficiency of large transformers. The principal asset of the manufacturer was low price. If he had a comparatively high efficiency, he was so much better off, but he could not sell a higher efficiency transformer at an appreciably higher price. This was partly due to lack of attention to the subject, lack of ability to use waste power, including lack of water and boiler regulation in hydro and steam systems respectively, and lack of money and money-borrowing power.

The first group of transformer buyers to pay much attention to efficiency was the primary power users. As the central-station industry grew in engineering and magnitude and borrowing ability it began to count the detailed costs, so that, while the overall cost of electrical energy has been going down, the capitalized sales value of high efficiency has been going up.

It is not within the scope of this article to explain the methods of capitalizing losses. When an attempt is made to translate transformer losses into dollars' charge, it involves considerations that vary widely for different users. The ratio of fuel costs to other costs may be two or three times as much in one station as in another. One user may allow only the fuel cost to enter into his calculations, another may give consideration to a large part or all of his other costs, and still another may employ two components, one based on capital charge depending upon equipment cost and the other based on fuel and other charges. Of course there is a very wide range of actual costs, and on this is imposed another wide range of accounting methods.

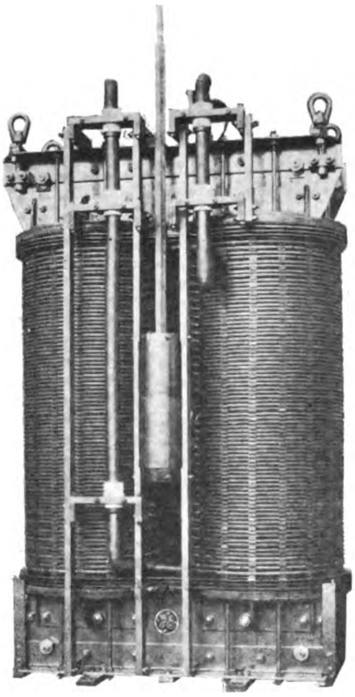


Fig. 5. High Efficiency Transformer Rated: Water-cooled, Single-phase, 60 Cycles, 20,000 Kv-a., 63,000/115,000–11,400 Volts

Since transformers seldom operate at full load continuously, it is important to consider the load cycle and the ratio of core loss to load loss. The core loss is constant in value at normal frequency and voltage, while the load loss varies as the square of the load. Therefore, the mean square of the load must be determined to get the total annual loss in kilowatt-hours. "Load-factor" alone is insufficient. Obviously, in comparing transformers for operation at less than unity load-factor and with the same total normal loss, the one with a lower ratio of core loss to load loss is superior.

The practice of capitalizing the core loss and the load loss separately is growing more common among transformer users. For example, the purchaser may capitalize core loss at $300 per kilowatt and load loss at $100 per kilowatt. In other words, he would be willing to pay $300 for a kilowatt reduction in core loss and $100 for a kilowatt reduction in load loss. Fortunately, the core loss is much less than the copper loss in a modern transformer of well-balanced design.

Increased Complexity of Design

The transformer is the connecting link which binds all of the integral parts of a power system together into one great commercial enterprise. It must be adaptable to the different voltages of the different transmission lines and to the various requirements and characteristics of generators, motors, synchronous condensers and converters, lamps, electric furnaces, etc. When it is necessary to interconnect different systems by means of transformers it must be done without disturbing the previously satisfactory functioning of the individual systems.

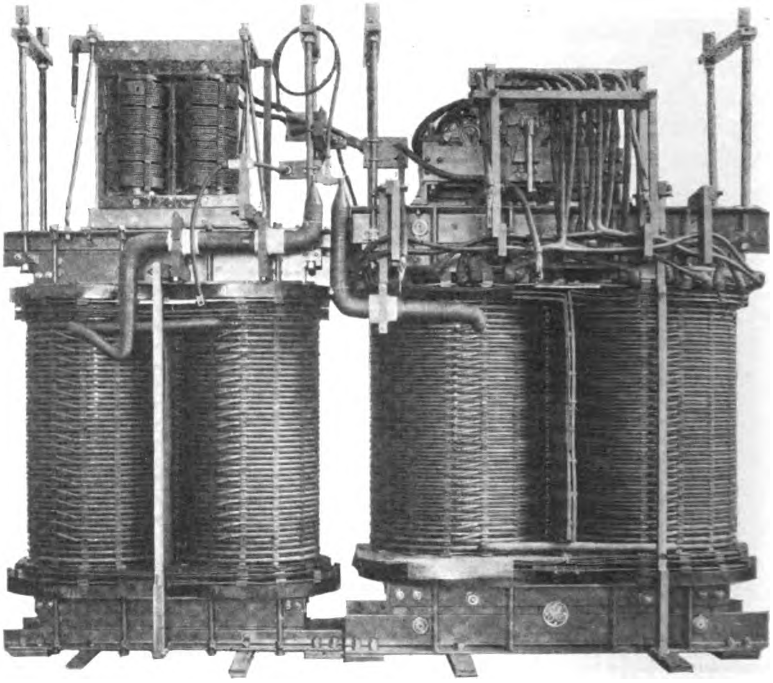


Fig. 6. Interior View of a Complex Transformer Used for Interconnection. It is rated: Self-cooled, single-phase, 60 cycles, 20,833 kv-a. (output), 120,000Y (GR)-120,000Y (GR)

Fig. 6 shows the interior view of a complex transformer used for interconnection.

The interconnection of systems and the growth of high-voltage networks are responsible for the development of "load-ratio control" (changing taps under load), three-winding transformers, and combination autotransformers and transformers, which have added great complexity to the design of many high-voltage transformers. The proportion of such transformers is increasing every year.

High-voltage distribution has resulted in many transformers having secondary windings of relatively high voltage. Secondaries of 33 kv. have been common for some years. Secondaries of 66 kv. are quite common. A large number of units are built for 132 or 220 kv. to 66 kv. Secondaries of 110 kv. are appearing and undoubtedly will be common in a few years.

Having both windings of high voltage adds to the physical size of the unit for a given kv-a. capacity, and since taps are frequently required in the secondary winding they add to the difficulty of the design.

High-voltage distribution with increasing length of feeders has resulted in feeders of higher reactance, thereby requiring transformers with a greater tap range in voltage. The customary 10 per cent range is no longer adequate in many cases and tap ranges of 15 to 20 per cent are being specified by some operators. This is unfortunate since it adds to the size of the transformer and unbalances the design. Obviously, it is impossible to maintain a perfectly balanced arrangement of the windings with respect to one another except on one certain voltage connection; and the greater the tap range, the greater the unbalance.

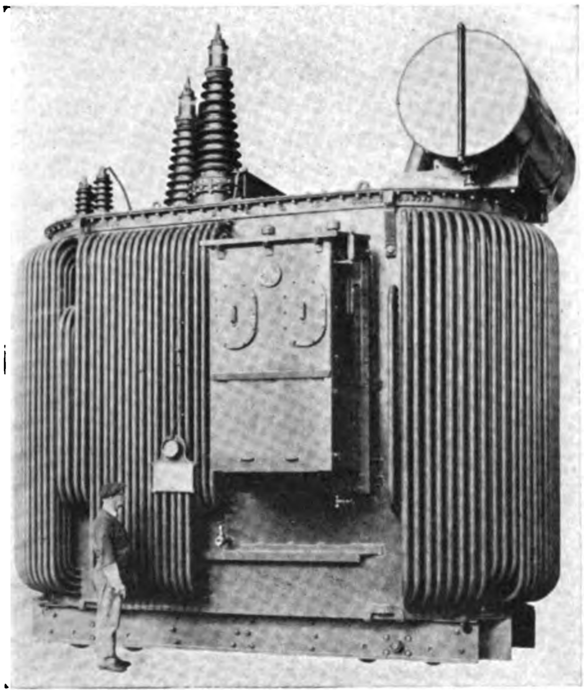


Fig. 7. Exterior of the Load-ratio-control Transformer Shown in Fig. 6. The operating mechanism is enclosed by the housing

Three-circuit Transformers

The first use—and what is still the most logical use—of the three-circuit transformer was to supply a local distribution at a voltage too high for a synchronous condenser, with a third winding for the condenser, thus effectively combining the functions of two transformers in one unit. Obviously a large saving results, since fewer switches are needed, less space is required, the installation cost is less, and the losses of a three-circuit transformer are materially less than two equivalent two-circuit transformers.

Another common use for three-circuit transformers is for interconnecting two systems or generating stations with the third winding for local distribution or for a synchronous condenser. Indeed, four-circuit transformers for this service are not uncommon and frequently such a transformer has an autotransformer connection for the interconnection. The added difficulties of designing such transformers are not generally appreciated. Usually a large tap is required and often the taps are in more than one winding. When reactance limitations are imposed, particularly for all three circuits, the design becomes exceedingly inflexible and difficult to accomplish.

Notwithstanding their extreme complexity and the difficulty of designing three-circuit and four-circuit transformers, particularly when they have large tap ranges or autotransformer connections, there appears to be ample economic justification for their use in many cases.

Load-ratio Control

The wider tap range and the requirements of interconnected systems with power flow in either direction have resulted in the development of transformers having their ratio capable of being varied while under load. Induction voltage regulators have been used for many years to hold constant voltage and also to vary the transformer ratio, but the voltage and kv-a. requirements for interchanging large blocks of power are beyond the economic range of induction voltage regulators.

Fig. 7 shows the exterior of the transformer which was illustrated in Fig. 6.

There are many variations in the details of design of load-ratio-control transformers, but every equipment consists essentially of a transformer with taps in one of the windings and means of shifting the connections from one tap to another without removing the transformer from the circuit or interrupting the load. They may be manually operated, remotely controlled, or fully automatic. The proportion of such units is rapidly increasing and at the present time more than 25 per cent, by kv-a. capacity, of all large transformers are provided with load-ratio-control equipment.

When it is necessary to connect two generating systems together by means of transformers and it is desirable to vary the ratio of transformation under load, it is common practice to place the tap-changing equipment in the low-voltage windings, or at the neutral end of the Y-connected high-voltage windings of the main bank of transformers, the whole being self-contained. Occasionally, it may not be desirable to provide the load-ratio-control equipment in the main units, in which case separate regulating transformers for bucking or boosting the voltage may be connected in series with the main bank of transformers. This scheme is very useful when the transformers have already been installed and the system growth requires ratio variation. Load-ratio-control regulating transformers may be installed in series with the main transformers at their neutral ends or directly in series with the line. Indeed, such regulating transformers may be inserted in series with the line at any desired point regardless of the location of the main power transformers.

When two generating systems are connected together, the exchange of power between them must be controlled by the governor settings of the respective prime movers. Local load requirements seldom permit an appreciable variation in the generator voltages and there may be an undesirable exchange of wattless current. The load-ratio-control transformer makes it possible to completely control or eliminate the exchange of wattless current between the systems without interfering with their respective local distribution of power.

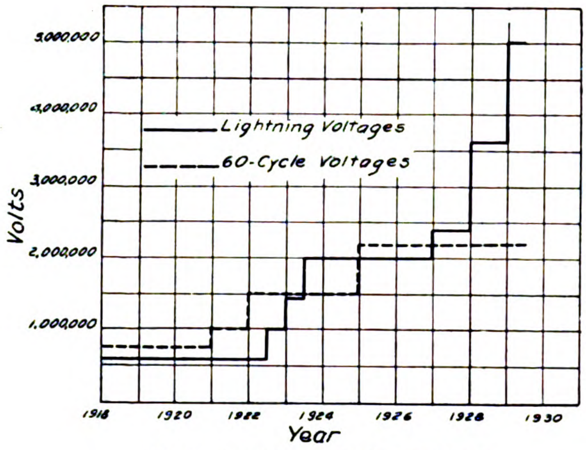


Fig. 8. Voltages Available for Research

Many cases arise when load-ratio-control transformers give satisfactory system operation where otherwise synchronous condensers would be indispensable. Even on systems well provided with synchronous condensers, load-ratio-control transformers will often prove very valuable in preventing useless circulation of wattless current over the system.

Although load-ratio-control transformers have greatly increased the burdens of the transformer designer, they have proved of immense value to the central-station industry and their use is bound to grow.

Lightning

There are thousands of miles of transmission lines running across the country in certain sections where electric storms are almost a daily occurrence on some parts of the vast systems. The transformer is the bulwark of insulation between these high-voltage systems and the generating stations, the distribution systems, and the ultimate consumers. Not only must the transformer insulate these lower-voltage circuits and apparatus from the high voltages of the transmission system itself, but it must also protect them from lightning voltages. Lightning need not strike a transmission line to endanger the apparatus connected to the line. If it strikes even a mile away, it induces excessively high voltages on the transmission line.

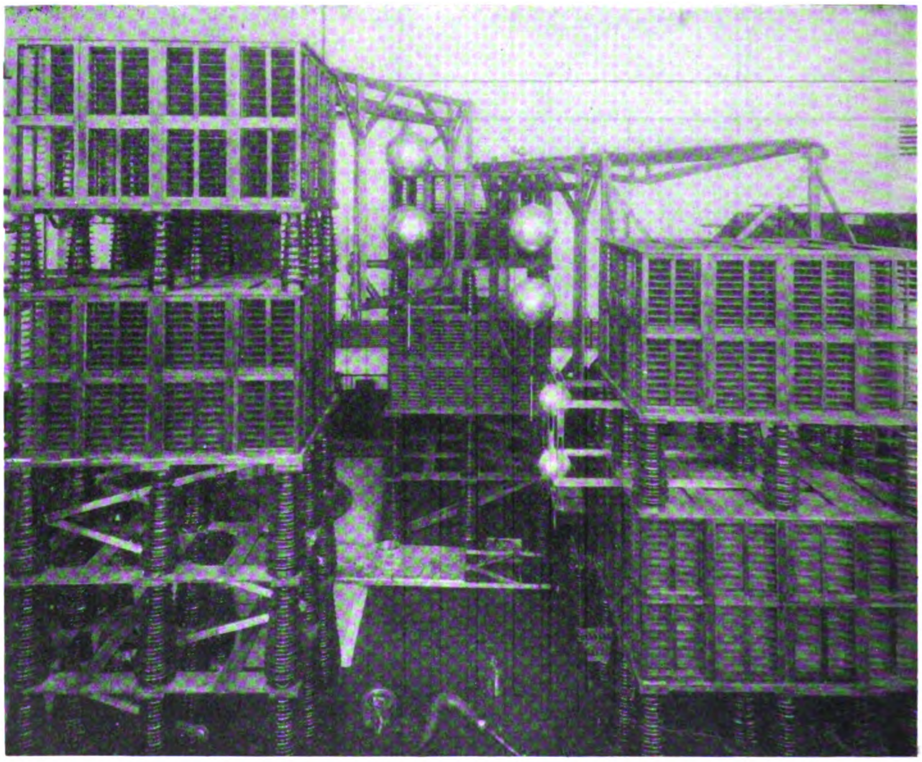


Fig. 9. View of the Lightning Research Laboratory at Pittsfield (Mass.) Showing Part of the 5,000,000-volt Generator

It is necessary to make a large number of tests on transmission-line insulation and transformers to be able to design them in a way that will protect the connected apparatus from the hazards of lightning. While some tests can and have been made with Nature's lightning, it is an extremely uncertain business. Nature's lightning cannot be depended upon. It refuses to be where wanted and when wanted. Therefore, for experiments it is necessary to have artificial lightning available and under control as to value, time, and location. Fig. 8 shows the maximum lightning voltages and 60-cycle voltages available for research by the transformer designing engineers. Fig. 9 shows a view of the lightning research laboratory.

The available lightning voltages of five millions, and 60-cycle voltages of two millions, are well above the maximum flashover values of the highest-voltage transmission lines. With them engineers are able not only to study existing requirements but also to prepare for possible future extensions in transmission voltages.

Coördination of Insulation

From the very beginning of the use of high-voltage transformers, it has been the practice to design them for a test of twice the line voltage. Although there have been many improvements in the internal insulation of transformers, particularly with respect to strength against impulse or lightning voltages, the standard test has remained the same.

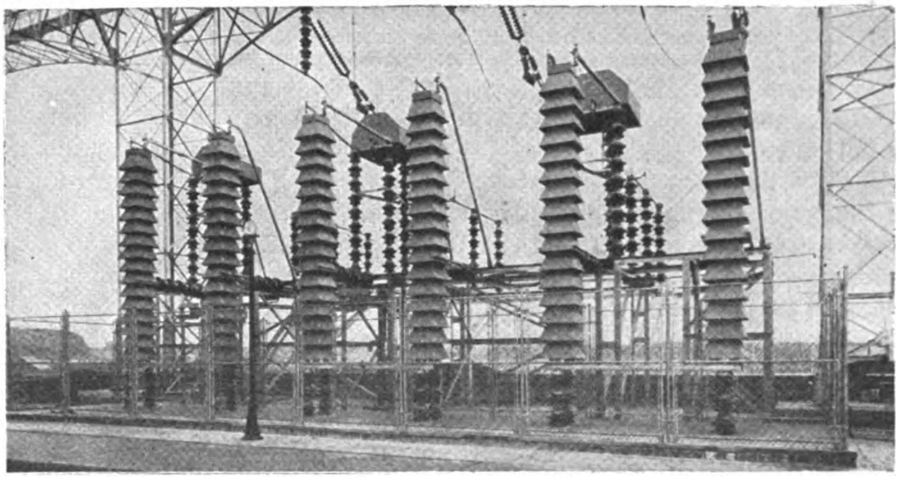
On the other hand there has been a decided tendency to increase line insulation, the purpose being to reduce the number of outages. The average 110,000-volt line today has very much greater line insulation than the average 110,000-volt line of 15 years ago. This practice might easily result in the transformer being the weakest point in the chain of insulation so that under lightning impulses it might be the first link to give way, obviously a very undesirable condition. Best modern practice dictates that the impulse strength of the transformer should be greater than the impulse strength of the line, at least that part of the line adjacent to the transformer. In addition, all possible precautions should be taken to provide adequate lightning protection so as to reduce the number of line outages.

Complications and Reliability

It has often seemed to transformer engineers that needless complications are often required by operators, as if the skill of the transformer designer were being invoked in order to avoid the more thorough engineering required to determine future needs accurately. It must be recognized however that no system is ever complete, and it is well-nigh impossible to make very accurate predictions of the future growth. Flexibility must be provided, and the transformer is the only place where it can be obtained at a reasonable cost. The transformer therefore becomes an electrical universal joint in the system and it is the transformer engineer's job to provide transformers with large tap ranges, series-multiple and autotransformer connections, three and four-winding constructions, load-ratio control, etc.

The transformer has long been considered a very reliable piece of apparatus, but it might be expected that modern complications in the requirements might introduce hazards that would seriously affect transformer reliability. However, records do not indicate that complications have adversely affected transformer reliability. Regardless of complications, well-designed transformers, built of the best obtainable materials by skilled, well-trained, and conscientious workmen, are the most reliable links in the modern electrical system.

Alert Guardians of Power Stations



Instantly ready to ward off the damaging stroke of lightning, oxide-film arresters stand guard at hundreds of power stations. These, installed at the Conowingo (Md.) hydroelectric station of the Philadelphia Electric Company's System, were the first to operate at 220,000 volts

The General Trend of Steam Turbine Development by the General Electric Company

Size of Units—Double-flow Units—Regenerative Cycle—Economic Rating—Higher Temperatures—Higher Pressures—Compound Units—Economic Indications—Heat Rates

By **ERNEST L. ROBINSON**
Turbine Engineering Department, General Electric Company

(*A paper delivered at the World Power Conference in Tokyo, Japan, October 29–November 7, 1929*)

THE rapid growth in the total capacity of steam turbines that have been installed for electric service on land during the last quarter of a century is indicated by the curve in Fig. 1 which represents the cumulative production of such machines since 1906 by the General Electric Company and which has now reached a grand total of twenty million kilowatts. (Units for ship propulsion and mechanical or gear drive are not included.)

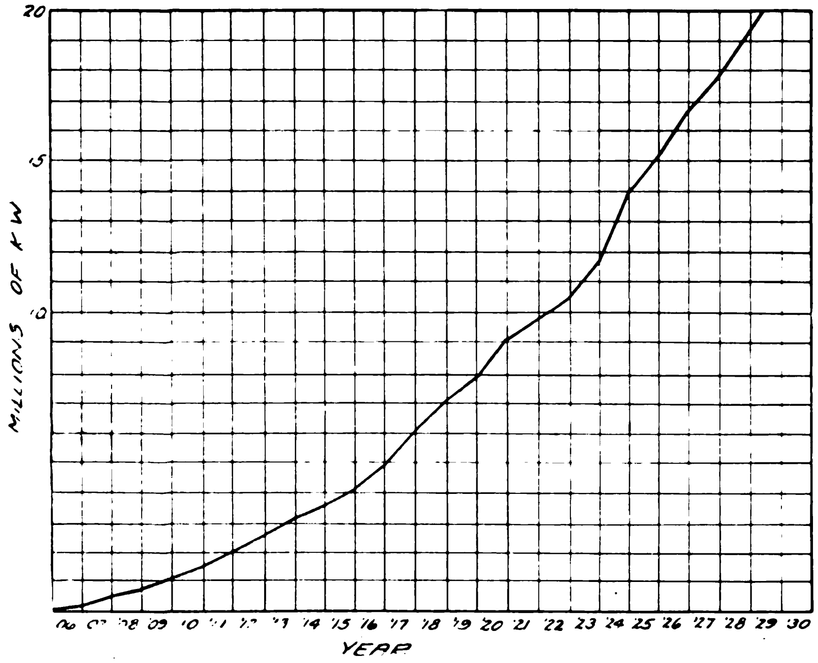


Fig. 1. Cumulative Shipments of General Electric Steam Turbines (Excluding Those for Marine and Mechanical Drives). In the remaining illustrations of this article, the curves also apply specifically to General Electric Turbines

Less than one-third of this construction occurred in the first half of the period. During the earlier part of this interval the owners of industrial plants and large central stations were mainly concerned with reaping the benefits of the increased capacity and economy of the steam turbine itself as compared with reciprocating engines; while during the latter part of the period great strides have been made in the economical application of the apparatus and its development as a thermodynamic machine. This development is still going on.*

The purpose of this article is to present what these developments have been during the past ten years, as reflected in the general trend of development of the steam turbine as manufactured by the General Electric Company. As this section of the World Power Conference is concerned primarily with the economic aspects of power generation, there is no intention of going into the technicalities of the subject but it is appropriate to point out at this time that the steam turbine itself, though known for thousands of years, was at last made a reality by the courage of those who had faith in the theory that it was not just a toy.

Similarly the growth of the past ten years has borne remarkable witness to the faith of the industry in the dictates of pure theory. Year after year, pressures and temperatures have been pushed upward by central-station constructors with perfect confidence that never before realized economies would be effected; and just as surely have the gains been accomplished. The only factors of uncertainty which had to be explored in the course of this growth, and the ones of greatest importance, were the cost of accomplishment and the degree to which the refinements of design dictated by theoretical considerations would be warranted in reduced cost of the finished product. By looking at what has happened in ten years, some light is thrown on what things have proved most valuable, and some judgment can be formed as to the possible trend in the immediate future.

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*It should be borne in mind that the statistics appearing in this article represent conditions existing prior to February 16, 1929, when the article was finished.—Ed.

Size of Units

The growth in the size of a unit is shown in Fig. 2. This is significant of a number of economic factors, particularly during the past ten years. Not only has the size of the largest unit constructed increased during the period under consideration but the general size of unit sold for central-station power generation has also increased. With this increase of size has come a diversification of type which illustrates one of the significant tendencies and also shows how the different factors contributing to the trend of development are interrelated. For the sake of argument it is convenient to discuss different factors separately but the facts of the case are that no one of the various contributing factors is independent of the others.

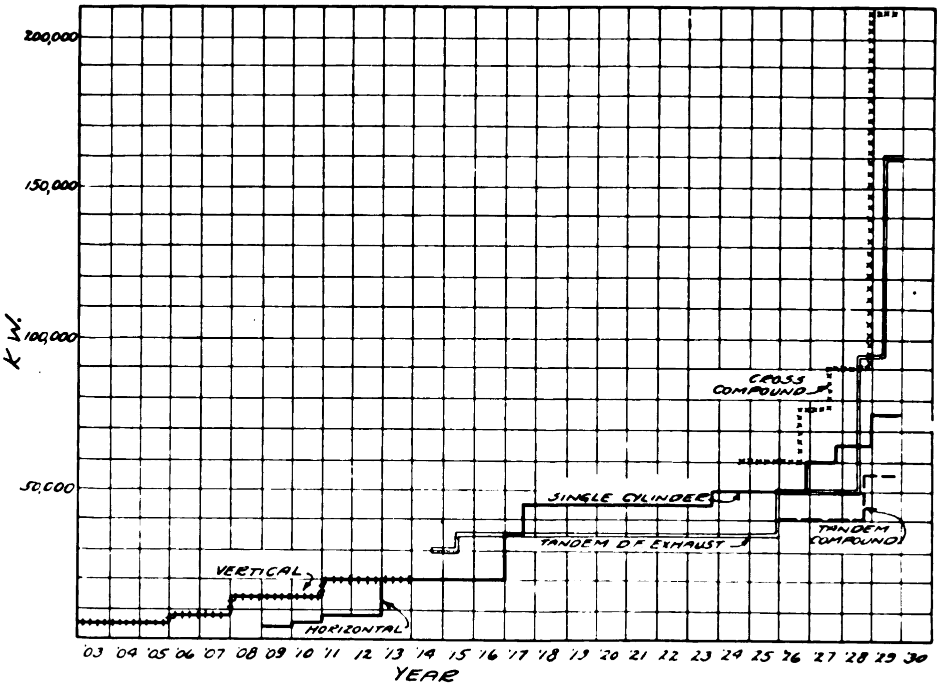


Fig. 2. Maximum Ratings of Turbines of Different Types

Ten years ago a 30,000-kw., 1800-r.p.m. unit was regarded as of up-to-date standard practice for central-station installation. At the same time a 35,000-kw. unit of 1500 r.p.m. and a 45,000-kw. unit of 1200 r.p.m. were not only the largest single units sold but also represented the standard types being manufactured. All of these machines were single-cylinder, condensing, non-extraction turbines operating on the straight Rankine cycle at pressures in the region between 200 and 300 lb. per sq. in. and at temperatures which had not yet begun to approach the limits for the strength of materials. For a considerable period there had been no radical departure in the matter of pressure or temperature, and the economies which central-station operators had been effecting were due to the installation of the then modern units in increasing numbers and the shifting of older machines to the stand-by class. The operator thus gained by using his new machines to the fullest extent and taking the peak loads on old equipment.

Double-flow Units

There were in operation at this time, as will be seen by reference to Fig. 2, a number of tandem units with double-flow exhaust stages. The reason for this design was as follows: The economic rating of a large machine is fixed by the leaving velocity loss from the exhaust wheel the size of which is limited by its stresses. The available vacuum must be considered since the losses due to exhaust velocity are much reduced at high back pressure on account of the greater density and smaller volume flow. When a very large size is desired with a high efficiency, double-flow construction is required in order to pass the large amount of steam without excessive losses at the exhaust.

The extra cost of this type of construction is not so great as might be expected. Its justification, if extra capacity is not required, depends on the saving in fuel, fuel handling, boiler and condensing installation. When the first machines of this type were built, it was for greatly increased capacity, in which case the extra investment charges on the whole plant per unit of increased capacity had to be compared with similar charges for a single-flow installation.

Ten years ago this type had already been exceeded by the single-cylinder machines so that no more were built until size requirements had developed to a higher degree when the same sound reason for its use again came into play and resulted in the recent larger capacity machines also indicated in Fig. 2.

Regenerative Cycle

Dealing now with those developments which have characterized the period during the past ten years, it is rather difficult to take them up in chronological order since in some respects they came on together.

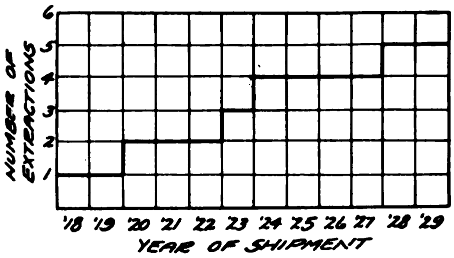


Fig. 3. Maximum Number of Extractions Used for Feed Water Heating

Of great importance was the more general adoption of the practice of extracting steam from the turbine for the express purpose of heating the boiler feed water, thus making use of the regenerative cycle. While this cycle had been known and used with compound engines, the great advantages inherent in the use of the steam turbine at high vacuum delayed the extensive use of the regenerative cycle until recent times. At first, steam was extracted at only one point and used in conjunction with the economizer to heat the feed water. Later, when the art of designing a station with regard to its entire system of heat balance became a matter of common observance, and the flue-gas air preheater supplemented the economizer, the practice of extracting at two and three points became common; and now as many as five points of extraction are used for giving a highly regenerative heat balance. Fig. 3 illustrates the increasing attention paid to the regenerative cycle.

The economic significance of this development is two-fold. At one and the same time it decreases the fuel consumption of the turbine per unit of electric energy generated and enables the same size of turbine to handle a distinctly larger capacity for the same investment. The improved heat efficiency may be thought of as due to the recovery of considerable quantities of low-grade heat transferred to the returning liquid circulation and relieving the furnace of a corresponding duty. The increased capacity available from the same turbine investment may be easily appreciated by noting that the condensing plant is, with the regenerative process, distributed through a number of units and able to draw steam from several points of the turbine shell instead of having to receive it through a single congested passage. The process thus enables the drawing of considerable quantities of excess steam through the shorter buckets of the turbine which are easily designed because the stresses in this case do not form any limitation and the additional cost is almost negligible.

Economic Rating

The steam-rate load curve of turbines built ten years ago commonly showed the most economical operating condition to be somewhat less than maximum capacity, with a single overload valve, and comparisons were made on the basis of performance at that single condition. Analysis of station load-factors showed owners that their machines were rarely operated continuously at the most economical load and that the daily and annual load-factors were far below 100 per cent. The service necessity of keeping some spare capacity at the beck and call of the swings of the governor, and the expediency of having this reserve in more than a single floating unit, resulted in calls for turbines designed to operate efficiently throughout the range of loads between 50 and 75 per cent of the maximum capacity. In other words, multi-valve machines are now required with a relatively flat load curve extending from 33 to 100 per cent load.

Modern turbines are thus sold on a heat-rate load curve basis adapted to the requirements of the purchaser so as to provide him with the best "integrated" efficiency, *i.e.*, the lowest heat consumption by the month regardless of the value at any individual point. Fig. 4 exhibits the heat-rate load curve for a machine of the sort described and shows, between 47 and 85 per cent load, a heat-rate rising not more than two per cent above the most economical condition at 70 per cent of the maximum capacity.

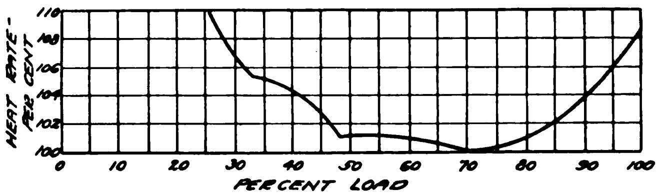


Fig. 4. Heat-rate Load Curve Representative of Modern Turbine Practice

This tendency has also had a sort of double significance because the provision of a reserve capacity at slightly poorer efficiency, to be used only on occasions, not only enables a better monthly fuel report but also enables the raising of the kilowatt capacity rating of the entire station with consequent reduction in investment charges per unit of installed capacity. In other words, the type of overload control demanded by the industry at present shows that it has been found unprofitable to pay high investment charges simply for occasional peak load capacity and that such reserve should be obtained at a reduced installation cost (represented by overload valves and corresponding requirements, and slightly reduced efficiency with overload) rather than at the same cost as the entire turbine plant at the highest efficiency.

Higher Temperatures

In 1917, the maximum initial temperature was raised after a period of nine years during which it had remained at 600 deg. F. Fig. 5 shows the trend rising steadily in the succeeding years until 750 deg. F. was reached in 1926. This represented the change from old practice when temperature was thought of as so many degrees of superheat to the modern viewpoint of using the highest temperature compatible with stability of the materials.

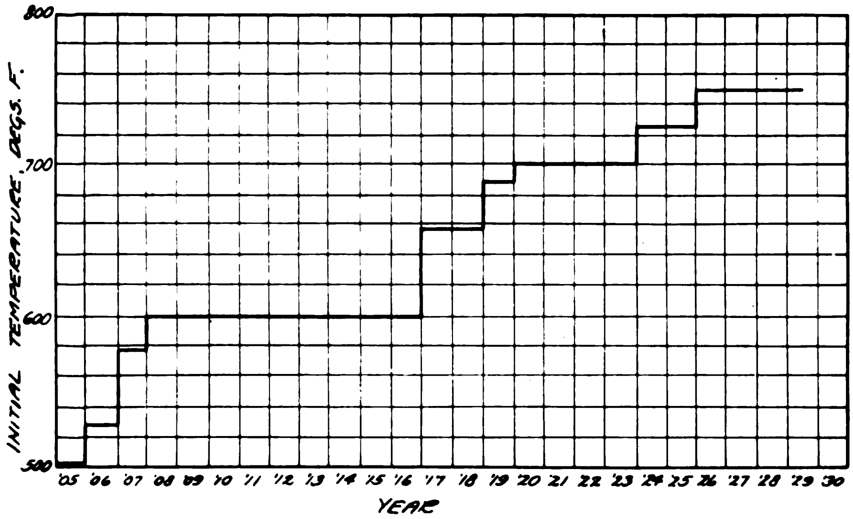


Fig. 5. Maximum Steam Temperatures for Turbine Operation

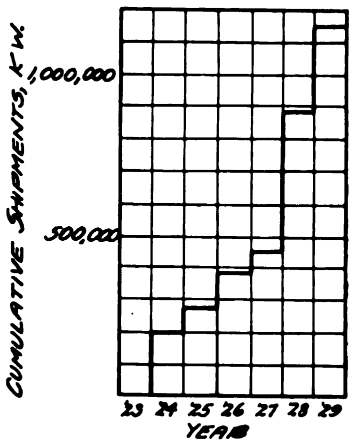


Fig. 6. Extent of Application of Resuperheating Turbines

The temperature of 750 deg. F. represents approximately the limit at which materials can be trusted to maintain dimensions under stress. Active researches are being carried on with the intention of raising this limit and there is perfect willingness at the present time to construct for 800 deg. F. under suitable conditions with respect to governing, pressure, temperature fluctuation, and degradation in the first stage of expansion.

While the differential of improvement in fuel consumption due to increased temperature is not great, it is of the order of one per cent for each 30 deg. F. increase, so that the shift of conditions from 1917 to 1926 represented an accomplishment of about five per cent due to this one item.

Resuperheating

The advantage of resuperheating is similar in degree to that obtained by increasing the initial temperature. Both processes benefit from the nonthermodynamic gain which is secured by decreasing the amount of moisture in the last few stages of the turbine and by decreasing the number of stages so affected. Fig. 6 illustrates the increasing favor with which purchasers of turbines regard this process. The 1929 total represents 19 units averaging just over 60,000-kw. capacity each.

The application of resuperheating is so closely interrelated with the high-pressure development now going on and with the development of large compound units that it is not proper to discuss this feature independently.

Higher Pressures

The tendency toward higher pressures has gone on side by side with the development of large compound units. These two features are among the most outstanding characteristics of the present trend. Fig. 7 shows the increase in maximum initial pressures from 365 lb. per sq. in. abs. in 1923 to 1215 lb. per sq. in. abs. in 1926.

The reason for this great stride is the theoretical improvement in the steam cycle due to the absorption of heat in the boiler at the higher temperature rendered possible by the greater pressure. Although there is no particular virtue in the pressure itself, the efficient use of water vapor as a working substance led to this development. The justification for this step lies in the success of the stations which have adopted it, as reflected in the subsequent trend of business. There are now in operation, or under construction by the General Electric Company, turbines of an aggregate capacity of 363,700 kw. for service at 1200 lb. per sq. in. pressure.

Compound Units

Comparing Figs. 6 and 7 with Fig. 2 it will be noted that the first large step toward higher pressures occurred simultaneously with the installation of the first resuperheating unit and also with the first large compound turbine. The use of higher pressures practically necessitates the use of the resuperheating cycle. A single expansion starting with high initial pressure would result in excessive moisture in the last stage of the turbine. Therefore, expediency as well as economic reasons dictated the resuperheating practice.

The first turbines installed to operate with this cycle were single-cylinder machines with provision made to take the steam from the shell at an intermediate pressure, return it to the boiler-room for resuperheating, and then return it to the turbine shell for its final expansion. At practically the same time a cross-compound unit was installed to operate under closely similar conditions.

The tandem-compound machines in Fig. 2, as originally shipped in 1925, were similarly arranged except there were two shells and two rotors all in line, the resuperheating being accomplished between the shells.

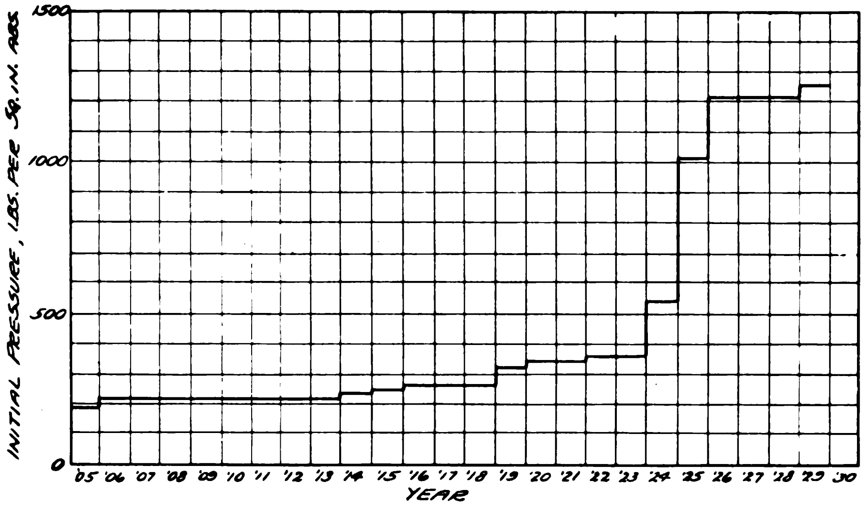


Fig. 7. Maximum Steam Pressures for Turbine Operation

However, the cross-compound machines have advantages particularly adaptable to use with high initial pressures and the resuperheating cycle, because the cross-over piping provides a convenient point for resuperheating and the shafts can be run at different speeds which has been found to contribute toward a high mechanical efficiency.

Thus at 1200 lb. per sq. in. initial pressure, the high-pressure element operates at 3600 r.p.m. and the low-pressure element at 1800 r.p.m. These improvements also tend to give a larger output in kilowatts for the same investment in turbine and condensing plant, because of the additional available energy in the heat cycle per pound of steam.

Economic Indications

It should be noted that the diagrams presented show *maximum* sizes and conditions for the years in question and should not be interpreted as implying that all construction is as indicated. The continuance of each trend shows simply that that development has justified itself to the purchasers under their particular conditions. Turbines are still being manufactured for operation at 250 to 400 lb. per sq. in. pressure for purchasers who feel convinced that those conditions are best for their location. Cheap fuel may not warrant an expensive installation, while a location where fuel is high may warrant a larger investment in turbine plant to secure improved efficiency.

While any particular case should be considered on its merits, it seems reasonable to infer from the results of the three years during which 1200 lb. per sq. in. turbines have been in operation, that no excessive or unanticipated expenses have been encountered and that expected economic gains have been realized. There is therefore a high degree of probability that in the future the tendencies will be in the direction of high-pressure installations where fuel costs are relatively high and the more inexpensive low-pressure installations where fuel is cheap. Intermediate pressures may become of less importance because analyses will fail to show economic advantages or disadvantage, and such pressures may come to be regarded as special.

Heat Rates

Statistics presented in the *Electrical World*(1) at the beginning of this year showed that the electric energy generated from steam power throughout the United States had more than doubled during a ten-year period while the coal burned had increased only a matter of approximately 20 per cent.

Fig. 8 presents the improvement in heat rate in General Electric steam turbines since the beginning of the business. For comparison, the heat equivalent of electric energy is indicated as well as the theoretical limitations of temperature inherent in the use of steam. The exact location of this limit, of course, depends on particular circumstances. However, the chart shows how nearly the heat rates of the best turbines now built approach the ideal condition. If economies are to be effected in the next decade beyond present accomplishments and at a rate corresponding to that during the past decade, the changes must be along new lines.

---

(1) *Electrical World*, Vol. 93, No. 1, "Progress and Statistical Number." Jan. 5, 1929, p. 53.

The more general installation of the modern equipment will, however, continue to show great improvements in station fuel requirements, such as reflected in the statistics referred to from the *Electrical World*.

The turbine owner has no interest in academic ideas as to internal efficiency. With regard to the nozzle or bucket arrangement, whereby the mechanical conversion of energy is accomplished, the application of any particular theory as to the mechanically most efficient type signifies nothing to him. What matters is the overall result obtained, which depends fully as much upon compliance with suppositions as upon any applied theory. It is for that reason that this article has dealt only with the results accomplished. When considering turbine performance, the practice of comparing internal efficiencies or turbine water rates is rather antiquated. The complex cycles now in use and the interchanging heat flow between the aqueous and gaseous circulation systems of the steam plant make a simple water-rate figure unrepresentative, and the present practice is to compare propositions on the basis of heat rates expressed in B.t.u. per kw-hr. chargeable to the turbine-generator unit. For this purpose it is necessary to agree upon a steam table.

The General Electric Company has made it a practice to base its calculations upon the published results of the Steam Table Committee of the American Society of Mechanical Engineers. This committee seeks close contact with all international authorities on the properties of steam and it is hoped there will be some internationally recognized standard in the near future.

Auxiliary Apparatus

During the period under discussion, appreciable improvements have been made in the electrical half of the turbine-generator set which cannot be passed over in view of the fact that the heat rates given in this article are based on switchboard energy and recognized generator losses. Three features in particular have been incorporated in recent apparatus: *viz.*, the use of external fans which are much more efficient than the older arrangement; the general use of air coolers in a closed circulation system and the return of the heat so recovered to the heat cycle; and the provision for hydrogen cooling, a feature already in operation with another type of electrical apparatus. The combined effect of these features is of no less importance than some of the steps of improvement noted in the thermal processes involved and one of the most important results has been the greatly increased capacity of a single turbine-generator unit.

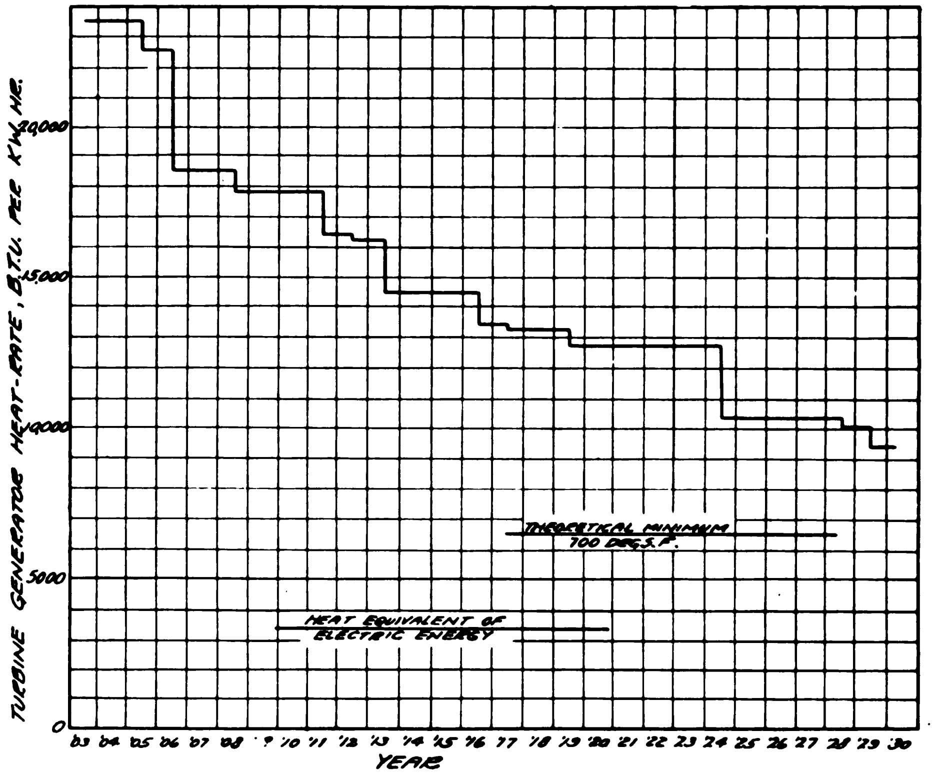
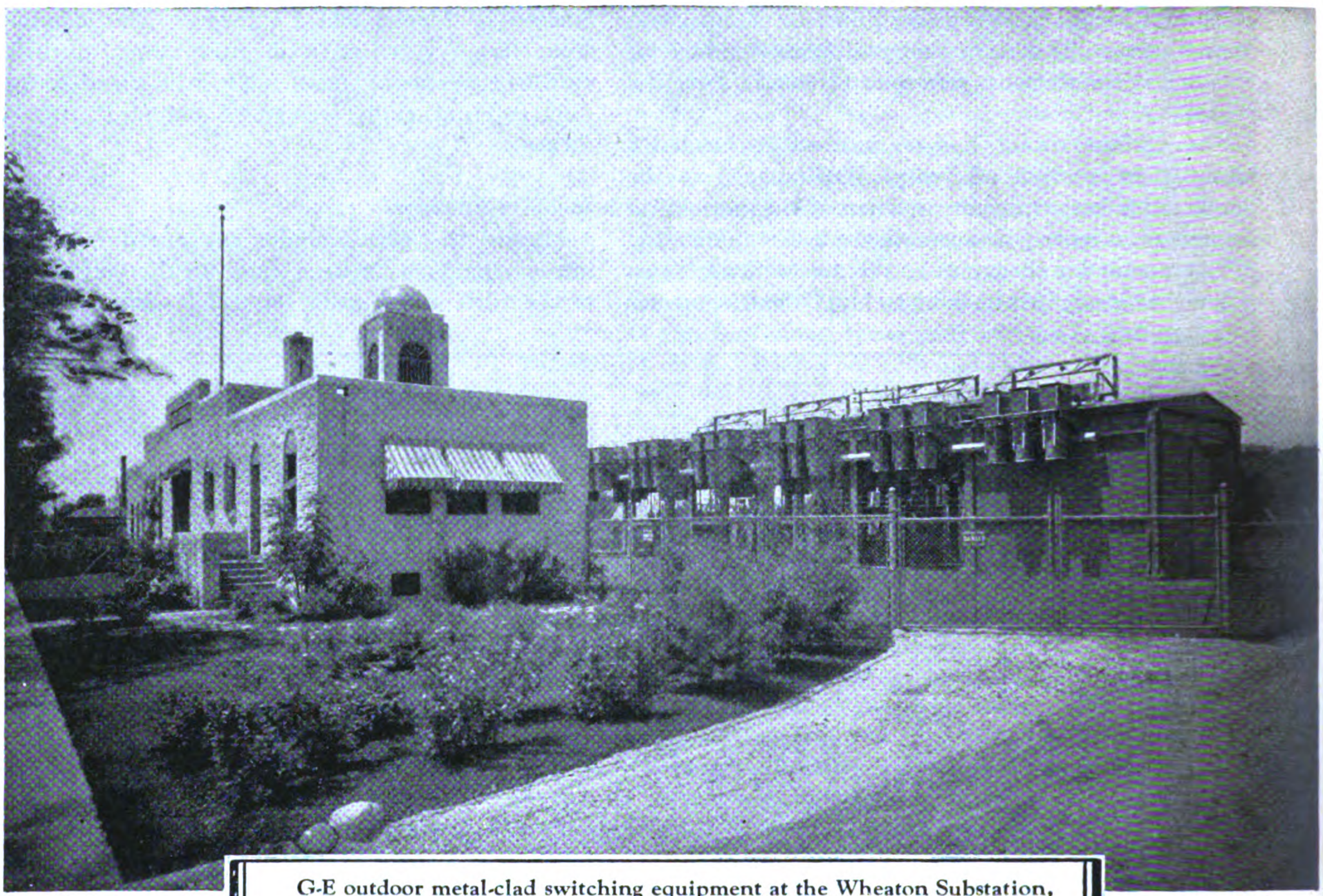


Fig. 8. Minimum Heat-rates of Turbines



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DR. IRVING LANGMUIR

President, American Chemical Society
Associate Director, Research Laboratory, General Electric Company

GENERAL ELECTRIC REVIEW

Vol. 32 December, 1929 No. 12

MADAME CURIE

> "Great mind and simple heart! Whose life" denotes
> "The grand humility of wisdom's ways."
>
> —*D'Albe*

"In science we should be interested in things, not in persons." Such appears to be Madame Curie's motto—a truly good motto and an excellent rule, Madame! But there are exceptions to most good rules; and when you honor us with a visit we cannot refrain, after expressing the utmost admiration for your life, work, and discoveries, from sending a word of respectful and affectionate greeting to the "Great Little Lady" from France.

As there is a streak of sentiment in us all, let us say frankly that America not only admires you, but loves you.

Even in America, the land of golden opportunities for those who start life's struggle under a great handicap, there is no story of "From Log Cabin to White House" to equal the romantic story of your life, work, and triumph.

The story of little Marie Sklodowska's early life and struggle in her belovéd, but persecuted, Poland; and of how she, without funds and without friends, went to study science in Paris is full of interest. Again, the story of her student life in a garret on the sixth floor; to which in winter she had to carry what little coal she could afford to buy, and where her simple and insufficient diet consisted of bread and milk, and of her having to earn her little wherewithal by private tutoring and by washing bottles at the Sorbonne, is so full of human interest that all who read it find tears in their eyes and a lump in their throat.

The story of her marriage to Pierre Curie and of their life and work together in the cause of science, under untold difficulties, privations, and hardships, but stimulated by a mutual love and by a common interest, is indeed "a poem round and perfect as a star."

The story of Madame Curie's triumph in finally discovering the two most wonderful of all the elements in Nature's architecture, and thus ushering in the newest, grandest, and most perplexing of all the sciences—the science of radioactivity—will enlighten, encourage, and thrill the world as long as history lasts. Her work has verily given us the key to subatomic mysteries, a better understanding of the stars, and a more perfect knowledge of the earth. Possibly her work may prove, in the future, to be the golden key which will enable man to unlock the stores of atomic energy, and put this titanic source of power at the disposal of future generations.

It is quite impossible to give here a real account of Madame Curie's work; it would take more space than we have at our disposal. For the same reason it is impossible even to outline the work of those other pioneers in science who laid the stepping stones of discoveries that finally led to her investigations. It should, however, be recalled that Konrad Röntgen had discovered that mysterious new light—x-rays—in 1895—when experimenting with a Crooke's tube. It was soon after Röntgen's startling discovery that Becquerel began his classical researches on uranium.

Professor Henri Becquerel, in studying the properties of fluorescent uranium, found that even when that element had not been exposed to light for months it still possessed the extraordinary property of affecting a photographic plate through black paper and even through thin metal.

Surely uranium must contain something that is perpetually giving out radiations somewhat akin to x-rays.

Professor Becquerel, knowing Madame Curie's extraordinary genius for making experiments and her profound knowledge of chemistry, asked her to undertake the investigation of what the mysterious "something" was. Becquerel had discovered that uranium also had the peculiar property of ionizing gases, and could, therefore, discharge an electrified body. By good fortune, Pierre Curie, Madame Curie's husband, had devised a highly sensitive electrometer apparatus, and, behold—here was just the tool they needed for their investigation!

It was soon discovered that pitchblende, the parent mineral in which uranium is found, contained something far more radioactive than uranium itself. The problem was to isolate and study this "something."

The procedure (leaving out tedious technicalities) was to take great masses of uranium-bearing ore and separate them chemically into various fractions. Then to test each fraction with the electrometer.

The most radioactive portion was again analyzed, reduced, and tested. But it took tons and tons of material and years of work before the magnificent final result was achieved. It is in those words—tons and tons and years—that the great story lies.

This gigantic and heroic work was all carried out in a leaky old shed in Paris, with absolutely no facilities for the work, no scientific equipment, and no heat in winter but what could be coaxed out of an old broken-down stove. But today we know that the equipment in that old shed in Paris was the best the world affords—the soul of all great accomplishments—Faith, Courage, and Character.

It was between 1895 and 1898 that the Curies were reducing their huge masses of material until finally the most radioactive part could be contained in their test tubes. Madame Curie records their inspiration and joy when sometimes they returned at night to the scene of their daily labor and saw their now luminous test tubes and bottles glowing in their dark shed laboratory. Verily, they were beholding a new "specter" that they themselves had liberated—a light that is destined to enlighten the world with a new knowledge of the universe.

How far this concentration of material was carried can best be told by stating that the final product did not amount to one millionth of one per cent of the original ore.

It was in May, 1898, after these years of Herculean labor, that Madame Curie could announce to the world that she had discovered and isolated a new element. She christened it Polonium to honor her beloved native land. Just as hardship had followed hardship and privation followed privation, so now was triumph to tread on the heels of triumph, for in the last month of that same year Madame Curie astounded the world by announcing the discovery of another new element, Radium, the most wonderful and perplexing of all the elements.

The discovery of Radium caused a blaze of scientific excitement throughout Christendom. It was two and a half million times more radioactive than uranium; so intensively active, in fact, that it is possible to detect the presence of one fifty-billionth of a gram.

Madame Curie proved it to be a new element by demonstrating the distinctiveness of its bright-line spectrum. Its atomic weight was found to be 226, and its place in the periodic table in the same group as barium, strontium, and calcium. It melts at 700 deg. C.

In 1910, Madame Curie succeeded in obtaining radium in the pure state. It proved to be a white metal, somewhat similar in appearance to calcium.

This remarkable element has the extraordinary properties of affecting photographic plates through metal, ionizing gases, exciting phosphorescence, liberating heat, effecting chemical changes, and destroying minute organisms.

Madame Curie has shown that a gram of radium, during every three-quarters of an hour, gives off sufficient heat to raise the temperature of an equal weight of water from the freezing to the boiling point. She estimates that two billion, nine hundred million calories of heat would be evolved by the disintegration of a single gram of radium.

As soon as the great discovery was announced some of the foremost scientists in the world began to investigate the remarkable properties of radium. Notable among them were Sir Ernest Rutherford and Sir William Ramsay and Professor Frederick Soddy. Rutherford was the first to give us an analysis of the complex radiations of all radioactive substances. He christened the three distinct types of rays emitted—the alpha rays, the beta rays, and the gamma rays.

The alpha rays were shown to be positively charged particles shot off at a velocity of about twenty thousand miles per second, and have since been proved to be positively charged atoms of helium.

The beta rays are streams of electrons and their velocities range from sixty thousand to one hundred and eighty thousand miles per second. They are identical with the cathode rays of a vacuum tube.

The gamma rays are waves in the ether, of the same general nature as x-rays, but of shorter wave length.

It has been estimated that in seventeen hundred and thirty years a piece of radium will have lost half of its weight and that in another seventeen hundred and thirty years the remainder will have lost half its weight, and so on.

In the solution and evaporation of radium salts an intensely active gas is given off. This gas is, indeed, itself another new element. It is called Niton. It is this gas which constitutes the much-talked-of radium emanation. And again it is this emanation of radium that is "harvested" in tiny phials and used by physicians as a therapeutic agent in combating diseases.

We should like to write more on this subject as we feel that these mysterious emanations of radium—the product of Madame Curie's work, may eventually prove of untold value in the biological world, and thus form one of her greatest contributions to humanity; but it is too deep a subject and too long to enter here.

Madame Curie had achieved one of the greatest triumphs of scientific research on record, had revealed to the world some of the innermost secrets of Nature, and had performed a remarkable service to humanity. It is therefore humiliating to have to record that years after her epoch-making discovery she had no radium of her own, not even a milligram—and, alas, no money to buy any. That such a condition could exist in our modern world, where the value of scientific research is supposed to be recognized, makes one sigh "what fools these mortals be."

It was due to the common sense, energy, and indignation of another remarkable woman, Mrs. William Brown Meloney, that this regrettable condition was changed. Mrs. Meloney is an American, and after learning the facts we have recorded, she came back to America and aroused the women of America to subscribe $100,000 to purchase a gram of radium for Madame Curie. It is a matter of history now how Madame Curie came to America in 1921 to receive this gift from the hands of President Harding. It is pleasing to record how her great heart and noble mind refused to accept it as a personal present and insisted that the gift be deeded to the Institute of Radium of Paris.

We have already written about the labors involved in extracting the first few milligrams of radium, but we feel that a digression is justified here to show our readers what a gram of radium really means. We take our data from Darrow's *Master Minds of Science*. He tells us that the gram of radium presented to Madame Curie by the women of America in 1921 required for its production six hundred tons of ore and the labor of 500 men for six months. And that is only a part of the story. The process of extraction consumed ten thousand tons of distilled water, one thousand tons of coal, and five hundred tons of chemicals.

We shall not dwell on Madame Curie's present visit to receive the gift of another gram of radium, again subscribed for by the women of America, because that event has so recently been fully written of in our daily newspapers. But we do wish to put on record our pride that she honored Schenectady with a visit.

Madame Curie has received many honors. After the tragic death of him who had shared her life and work, she was appointed to fill the Chair of Physics that had been especially created for him at the Sorbonne.

In 1900, Madame Curie and her husband shared the Nobel prize with Professor Henri Becquerel. In 1911, she was the sole recipient of that much-coveted honor.

To be perfectly frank, we care no more for Madame Curie's titles than she does herself. We know and acknowledge no greater title than her name. The name, "Madame Curie," shall ever be enshrined in our hearts as something greater and more worthwhile than any titles that Presidents, Emperors, and Kings have the power to bestow.

To express our sentiments let us paraphrase those lines published in *Punch* when a famous German physicist died untitled by his Emperor. We shall simply substitute the name of Curie for that of Helmholtz.

"What matter titles? Curie is a name
That challenges alone the award of fame!
When Emperors, Kings, Pretenders, Shadows all,
Leave not a dust-trace on our whirling ball,
Thy work, oh grave-eyed searcher, shall endure,
Unmarred by faction, from low passion pure."

J. R. H.

Modern Concepts in Physics and Their Relation to Chemistry

By DR. IRVING LANGMUIR
President, American Chemical Society
Associate Director, Research Laboratory, General Electric Company

(Presidential address before the 78th meeting of the American Chemical Society, Minneapolis, Minn., September 11, 1929)

ONLY about 35 years ago, during the nineties of of the last century, knowledge of the physical sciences had advanced to such a point that many of the foremost physicists and chemists began to believe that the rate of progress of fundamental knowledge must be slowing up. The concepts of length, mass, time, energy, temperature, electric and gravitational fields, etc., had been given precise meanings and were regarded as having an absolute existence quite as certain as that of matter itself. The phenomena of nature were explainable in terms of natural laws expressing relations between these absolute quantities. It seemed that the most important of these laws of physics and chemistry had already been discovered and that the work that remained to do was largely a matter of filling in the details and applying these great principles for practical purposes.

The laws of mechanics had been verified experimentally with a high degree of precision so no one doubted that they were rigorous laws of nature. Back in about 1830, Hamilton had succeeded in generalizing these laws in a few simple equations which seemed to contain all the essential truths of mechanics. It was only necessary to know how the kinetic and potential energy of any given system varied with the momentum and the coördinates of its parts in order to have at least a formal solution of the way in which the system would behave at all times. Thus all future work in mechanics need only be considered an application of Hamilton's equations.

Complete knowledge of the nature of light presented more difficulties. Hamilton, about 1820, showed that all the known laws of geometrical optics could be explained quantitatively in terms of either a corpuscular theory of light or a wave theory. The experiments of Fresnel on the interference of light, which were made about this time, seemed to disprove Newton's corpuscular theory, so that Hamilton's proof of the complete analogy between waves and corpuscles in the case of geometrical optics became only of academic interest. Through the study of the phenomena of interference, diffraction, polarization, and absorption of light, the wave theory of light became firmly established. Light was supposed to consist of waves in some sort of an elastic medium which was called the ether.

About 1830, Faraday developed clear conceptions regarding the electric and magnetic fields and Maxwell, about 1860, by applying exact mathematical methods evolved the electro-magnetic theory of light according to which light waves consisted of fluctuating electric and magnetic fields which are propagated through space at a speed which could be calculated from electric and from magnetic measurements in a laboratory.

Although the acceptance of Maxwell's views came slowly, one could not long remain skeptical after the production of electro-magnetic waves of relatively great wave length by Hertz in 1884. It may almost be said that Maxwell's theory was essentially an application of the mathematical methods which Hamilton had originated in his treatment of the laws of mechanics, to Faraday's concepts of electricity and magnetism.

Thus in 1895, the physicists seemed to have some justification for the attitude that the most important laws had been discovered. The laws of mechanics had not been improved upon in 65 years. Faraday and Maxwell had brought in precise conceptions of electric and magnetic phenomena and had shown that by classical methods like those which had been so successful in mechanics, all the laws of optics could be derived from those of electro-magnetism.

In chemistry a somewhat similar state had been reached. After the evolution of the conception of the elements and of combining proportions based upon an atomic theory, rapid progress was made in accumulating data regarding the elements and their compounds. Faraday's laws of electrolysis and new methods for the accurate determination of atomic weights began to provide the chemist with quantitative laws almost as precise as those of the physicists. The work of J. Willard Gibbs had brought into chemistry rigorous laws as fundamental in their field of application as were those of Hamilton and Maxwell in physics.

These remarkable advances on the quantitative side seemed to overshadow in importance the more qualitative results that had previously been obtained through the stimulus of the atomic theory. Under the leadership of Ostwald, chemists began to adopt a much more critical attitude and began to distinguish carefully between what they considered experimental facts and hypotheses based upon these facts. Ostwald, although he recognized the convenience of the atomic theory, believed it must always remain impossible to prove the existence of atoms or molecules. He therefore urged that chemists avoid as far as possible the use of such hypotheses. Perhaps the chief result of this attitude was to lead physical chemists to neglect those parts of chemistry where the atomic theory would have been most helpful and to devote themselves more specially to the fields in which energy relationships and thermodynamics were directly applicable.

Physicists in general did not doubt the existence of atoms and molecules, but had by means of this theory developed the kinetic theory of gases which had led to many new quantitative laws, verified by experiment. However, the physicists in general had little to do with atoms and molecules but were more concerned with the ether, in which they believed unreservedly, although direct knowledge of the ether was far harder to obtain than knowledge of atoms and molecules.

Perhaps one of the main reasons why the physicists were so sure of the ether and the chemists so doubtful of the atoms and molecules was an unconscious belief in the respectable old adage "*Natura non facit saltum.*" Nature makes no jumps. Certainly in those fields of physics and chemistry in which rigorous quantitative laws had been found applicable no discontinuities or jumps such as those implied by the atomic theory had been found.

The discovery of x-rays by Roentgen, in 1905, marked the beginning of an extraordinary revolution which is today still in progress. This sensational event revealed to the physicist that great and fundamental discoveries were still possible even in the field of radiation where physics had had such complete success. It immediately caused great numbers of physicists to study the phenomena of electric discharges and to look for other sources of radiation. The discovery of radium and radioactivity by Becquerel and the Curies soon showed the importance of these new forms of radiation to the chemist as well as to the physicist.

Although Stoney in 1874 had seen that Faraday's laws of electrolysis together with the atomic theory required that electricity should also have an atomic structure, and although in 1891 he proposed the name electron for these atoms of electricity, J. J. Thomson should be regarded as the discoverer of the electron. He was able to show that electrons were contained in all forms of matter and found that the electron must weigh only about 1/1800 as much as a hydrogen atom.

The studies of radioactivity, largely by Rutherford and his students, showed that radium spontaneously disintegrated to form helium and proved to the chemist that atoms were not indestructible and even that transmutation of elements was possible.

By the application of thermodynamics to radiation processes Boltzmann proved that the total radiation, of all wave lengths, within a cavity in a heated body must increase in proportion to the fourth power of the absolute temperature; this law had already been found empirically by Stefan. By a further development of thermodynamic methods Wien, in 1896, derived an important law, known as Wien's law, by which the intensity of radiation of any particular wave length could be calculated in terms of the wave length and temperature. This law was found to agree with experiment in the case of visible radiation from incandescent solids, but serious discrepancies were observed when an attempt was made to calculate the intensity of infra-red radiation or heat waves. Lord Rayleigh and Jeans in 1900, using what seemed to be unimpeachable methods based on the electro-magnetic theory of light, arrived at an entirely different relation between the intensity of radiation and the temperature and wave length. This equation agreed excellently with experiments on the radiation of heat where Wien's law had failed but led to absurd results when applied to the shorter wave lengths of the visible spectrum. In fact, if the total radiation including all wave lengths were calculated from the Rayleigh-Jeans equations an infinite radiation density was obtained even at low temperatures. Thus by means of the classical theories of radiation it was found on the one hand by Boltzmann that the radiation increased with the fourth power of the temperature, and on the other by Rayleigh-Jeans, that the radiation was infinite at all temperatures.

It was shown in 1905, by Planck, that this paradox could be solved only by assuming an essential discontinuity in the energies or motions of electrons whose vibrations caused the radiation. This gave birth to the Quantum Theory, which within recent years has grown to be one of the most important theories of physics and chemistry. In 1906, Einstein showed that the photo-electric effect and many photochemical reactions could be explained in terms of the Quantum Theory if light itself consisted of discrete particles of energy or quanta, now usually called photons. Although such a corpuscular theory of light seemed utterly incompatible with the accepted wave theory an increasing number of phenomena were discovered in which it seemed necessary to resort to this corpuscular theory. The really rapid development of the Quantum Theory, however, dates from 1913, when Bohr began to develop his theory of atomic structure by applying the Quantum Theory to Rutherford's more or less qualitative theory of the nuclear atom.

Relativity Theory

Among all the changes in the ways of thinking which were being forced upon physicists at this time, the most important by far was that which resulted from Einstein's relativity theory, first stated in 1905. In 1895, as we have seen, electromagnetic waves and matter were thought to be manifestations of the properties of an all pervading ether.

As an example of the way that the physicists thought of the ether I will quote from the preface to Lord Kelvin's *Baltimore Lectures*. This preface was written in 1904, but the lectures were those that were delivered at Johns Hopkins University in 1884.

> "I chose as subject the 'Wave Theory of Light' with the intention of accentuating its failures; rather than of setting forth the admirable success with which this beautiful theory had explained all that was known of light before the time of Fresnel and Thomas Young, and had produced floods of new knowledge splendidly enriching the whole domain of physical science. My audience was to consist of Professorial fellow-students in physical science .... I spoke with absolute freedom and had never the slightest fear of undermining their perfect faith in ether and its light-giving waves; by anything I could tell them of the imperfection of our mathematics; of the insufficiency or faultiness of our views regarding the dynamical qualities of ether; and of the overwhelmingly great difficulty of finding a field of action for ether among the atoms of ponderable matter. We all felt the difficulties were to be faced and not to be evaded; were to be taken to heart *with the hope of solving them if possible*. .... It is in some measure satisfactory to me and I hope it will be satisfactory to all my Baltimore coefficients still alive in our world of science, when this volume reaches their hands to find in it dynamical explanations of every one of the difficulties with which we were concerned from the first to the last of our twenty lectures of 1884. All of us will, I am sure, feel sympathetically interested in knowing that two of ourselves, Michelson and Morley, have by their great experimental work on the motion of ether relatively to the earth, raised the one and only serious objection against our dynamical explanations."

This Michelson and Morley experiment of 1887, through the theoretical investigations of Lorentz and others, kept growing in importance until it finally stimulated Einstein to evolve his relativity theory.

According to this theory space and time cannot be considered as existing independently of each other. They cannot in any sense be regarded as absolute but are both dependent upon the point of view of the observer. For example, Einstein showed that it has no meaning to say that two events which took place at a great distance apart occurred simultaneously. Some observers knowing of both events would have to say that event A occurred before B, while other observers moving at a different velocity from the first observers would conclude that B occurred before A.

It is not my plan to try to explain the relativity theory to you even if I knew how to do so, but it is rather to discuss the way in which this theory and others of a somewhat similar nature have gradually brought about profound changes in the viewpoint of the physicists and how similar changes are beginning to occur in the attitude of the chemists. The importance of Einstein's work thus lies not so much in the facts or phenomena that can be explained by the relativity theory, but in the discovery of a new way of thinking as applied to physics. Somewhat similar methods of thought had, it is true, been used in some branches of mathematics and sometimes in philosophy, but Einstein subjected our elementary conceptions of space, time, mass, energy, etc., to a searching analysis quite new in the history of physics.

Concepts Involve Operations

Professor P. W. Bridgman of Harvard University has recently written a popular book entitled "The Logic of Modern Physics," in which he analyzes the changes in our concepts that have resulted primarily from Einstein's work. Bridgman's thesis is that *physical concepts have meaning only in so far as they can be defined in terms of operations*. He shows that this new attitude toward our fundamental conceptions is perhaps one of the greatest changes that has been brought about by Einstein's work. There is no question in my mind but that the recent remarkable advances in quantum mechanics that have been made by such men as Bohr, Heisenberg, Schroedinger, and Dirac have been stimulated by the desire to formulate all concepts in terms of operations. Bridgman has not originated this method, but he, more than anyone else, perhaps, has been conscious of its widespread application in modern physics.

I should like to outline to you the way in which Bridgman develops this thesis and to consider how well it applies to the most recent changes that have taken place in physics and in chemistry. I believe the chemist can derive great benefit from the conscious application of a similar critical attitude in his own science.

Bridgman points out that "hitherto many of the concepts of physics have been defined in terms of their properties." An excellent example is Newton's concept of absolute time. The following quotation from Newton's *Principia* is illuminating:

> "I do not define Time, Space, Place, or Motion, as being well known to all. Only I must observe that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which, it will be convenient to distinguish them into Absolute and Relative, True and Apparent, Mathematical and Common.
>
> "(1). Absolute, True and Mathematical Time, of itself, and from its own nature flows equally without regard to anything external, and by another name is called Duration."

Thus, according to Newton, time and space have properties of a very abstract kind and are looked upon as "things" which exist independently of all other things. There is, however, as Bridgman says, "no assurance whatever that there exists in nature anything with properties like those assumed in the definition, and physics, when reduced to concepts of this character, becomes as purely an abstract science and as far removed from reality as the abstract geometry of the mathematicians." Nevertheless, these conceptions of space and time prevailed until the relativity theory was proposed.

In the development of his theory Einstein, in analyzing the concepts of space and time, considered what means are available by which an observer can measure distances between two points on a rapidly moving object. For example, imagine two planets moving past each other at high velocity and two observers, one on each planet, provided with means for observing each other and communicating with each other; such means, for example, as light signals. Einstein asks, what are the operations by which the two observers could compare their units of length and time? He finds that each observer would logically conclude that the other observer's unit of length is shorter than his own, and that the other's unit of time is longer than his own. Einstein thus proved that there can be no such thing as absolute length of time, or rather proved that the concept of absolute time has no meaning, for we have not been able to conceive of any method for determining the absolute time of any event.

In order to illustrate his thesis Bridgman considers in detail the concept of length. Probably one of the earliest concepts of length was obtained by counting the number of unit lengths that can be placed end to end between two given objects. For example, the number of paces are counted in walking from one object to another. An extension and refinement of this method is employed today when the standard meter at the Bureau of Standards is compared with a steel tape and this is then used to lay off a base line for a survey by triangulation.

As Bridgman suggests, it was one of the greatest discoveries of the human race to find that these operations performed with a measuring rod afford a useful and convenient means of describing natural phenomena.

During the transition from the earliest pacing of distances, to our modern refined measurements with the meter stick, the concept of length itself must have undergone radical modifications since the operations involved had been modified. For example, if distances are to be paced, it has no meaning to consider distances of 1/1000 of a pace unless the concept is modified to include arbitrarily chosen methods by which a length equal to 1/1000 of a pace may be determined. In our modern measurements with a steel tape we must measure the temperature of the tape and the force used in holding the tape taut, and then by means of the coefficient of expansion and the coefficient of elasticity, apply corrections to the observed length. It is hard to see what methods primitive man could have used in applying such corrections to his distances measured by pacing.

Why do we now apply such corrections? Merely because it has been found by experiment that the result that we get by applying such corrections is a quantity which proves to be more useful in describing natural phenomena than the results we get without these corrections. We must not think that we do it in order to obtain the "true" or "absolute" length.

Today we have many other methods of measuring length than by use of measuring rods or steel tape. For example, we use optical instruments and measure distances by triangulation, we measure heights in the atmosphere by means of a barometer, we measure the distances of spiral nebulae by measuring the brightness of the Cepheid variables observed in them by our most powerful telescopes, we measure the lengths of molecules by finding the area of a water surface over which a given amount of oil will spread, we calculate the diameters of molecules by measurements of the viscosity of gases by means of the kinetic theory, or we use x-ray diffraction patterns or, finally, we calculate the diameter of an electron from its mass and charge by means of the electro-magnetic theory, assuming that all the energy of an electron lies in the electric field outside of its surface.

Now each of these measurements of length involves an entirely different set of operations and, therefore, fundamentally, according to Bridgman, we should regard them as different concepts; logically, in fact, they should all have different names. It has, however, been found as a matter of experiment that two or more of these methods when applied to the measurement of the same distance give results which agree more or less with one another. This, then, is our justification for calling all these concepts by the same name, length.

We may, if we wish, extrapolate and predict that by applying suitable corrections to each of these methods of measuring lengths we may be able to get better and better agreement between them. Such methods of extrapolation may be useful and stimulating but we must always expect that sooner or later we will be unable to obtain agreement between these methods with more than a limited degree of accuracy. This may not be due merely to experimental difficulties but may often result from unavoidable fuzziness in the concept itself. Such concepts as the diameter of a complicated molecule, or the mean free path of a molecule in a gas are inherently fuzzy conceptions and can mean not much more than when we speak of the diameter of a tree or of the length of the waves during a storm at sea.

Perhaps the strongest reason for the general belief in the existence of an absolute space lay in the apparently perfect agreement between our measurements of length and the theorems of Euclidian Geometry. During the last century, however, mathematicians began more and more to realize that Euclidian Geometry was only one out of many possible logical geometries, and since, all of these were based solely on certain axioms or postulates none of them had any real or necessary connection with physics. The apparent agreement between our physical observations and Euclidian Geometry, therefore, does not prove that space must have the properties postulated in Euclid's axioms.

Models

As chemists we are all more or less familiar with various models of atoms and molecules that have been proposed within recent years. The structural formulas which the organic chemists have used for a good part of a century are another example of an extremely useful type of model. I want to discuss later some of the models which the physicists have used in giving more concrete forms to their theories. Logically, I believe, we should regard Euclidian Geometry as a model devised primarily to help us "explain" natural phenomena.

Observations of nature reveal great complexity. We receive enormous numbers of impressions simultaneously and if we are to make progress in understanding phenomena we must concentrate on certain aspects of the things we see about us, and thus discard the less important features. This involves a process of replacing the natural world by a set of abstractions which we have become very skilful in choosing in such a way as to aid us in classifying and understanding phenomena. Thus it was found useful to develop concepts or abstractions such as shape, position, distance, etc., and separate these characteristics of the phenomena from others such as color, hardness, etc. Euclidian Geometry was found useful in correlating these concepts of shape, position, etc.

Physicists and chemists have usually felt that they understood a phenomenon best when they could explain it in terms of a model or concrete picture. The chemist explained the law of multiple combining proportions in terms of atoms which combine together to form molecules. The heat, conductivity, viscosity, etc., of gases was explained in terms of the kinetic theory, with molecules making elastic collisions with one another according to the law of probability.

When we use the atomic or molecular theories to explain phenomena in this way, we assign to the atoms and molecules only those properties which seem needed to accomplish the desired result, we do not consider what the atom is made of nor what its structure is, but usually feel justified in assuming properties which are as simple as possible. For example, in the elementary kinetic theory it is assumed that the molecules are hard, elastic spheres, not because anyone really believes that molecules have these properties, but merely because these are the simplest properties we can think of which are consistent with the known facts.

What we really do, therefore, is to replace in our minds the actual gases which we observe and which have many properties which we do not fully understand by a simplified model, a human abstraction, which is so designed by us that it has some of the properties of the thing we wish to displace.

There is thus a difference of degree rather than of kind between the adoption of a mechanical model and the development of a mathematical theory such as Euclidian Geometry. When the mathematical physicist develops an abstract theory of actual phenomena, for example, Hamilton's equations to summarize the laws of mechanics, he is in reality constructing a mathematical model. Mathematical equations have certain definite properties or rather they express certain relationships between the symbols which enter them. In a mathematical theory of physical phenomena the equations are so chosen that the relation between the symbols corresponds in some simple way to that which is observed between measurable physical quantities which are the bases of our concepts of physics.

Within recent years, especially in the development of the relativity and quantum theories, physicists have been making increasing use of mathematical forms of expression, and have been giving less attention to the development of mechanical models. The older generation of physicists and chemists and those among the younger men who are less skilled in the use of mathematics are inclined to believe that this is only a temporary stage and that ultimately we must be able to form a concrete picture or model of the atom, *i.e.*, to get a picture of what the atom is really like. It seems to be felt that a mechanical model whose functioning can be understood without the aid of mathematics, even if it only gives the qualitative representation of the phenomena in question, can represent the truth in some higher sense than a mathematical theory whose symbols perhaps can be understood only by a mathematician.

There is, I believe, no adequate justification for this attitude. Mechanical models are necessarily very much restricted in scope. The relationships of their parts are limited to those that are already known in mechanics (or in electricity or magnetism). Mathematical relationships are far more flexible; practically any conceivable quantitative or qualitative relationship can be expressed if desired in mathematical form. We have no guarantee whatever that nature is so constructed that it can be adequately described in terms of mechanical or electrical models; it is much more probable that our most fundamental relationships can only be expressed mathematically, if at all.

In analyzing our attempts to describe nature, we have discussed concepts, models, and mathematical theories. We find that they are all alike in that they represent human abstractions which are found convenient in describing nature. Going back a step further we must recognize that *words* themselves constitute elementary concepts. They are, it is true, much more vaguely defined than our concepts of physics and chemistry, but qualitatively they are very much like the latter; in fact, most of our misunderstandings in science arise from assigning reality to concepts whose main reason for existence is the fact that they are represented by a word. Logically we should aim to define our words in terms of operations. We should have in mind specifications by which we can test whether or not the word is properly applicable.

The progress of science depends largely upon (1) giving to words meanings as precise as possible; (2) definition of concepts in terms of operations; (3) development of models (mechanical or mathematical) which have properties analogous to those of phenomena which we have observed.

Meaningless Questions

A great deal of time and effort is wasted in scientific circles as well as in the world at large through failure to give sufficiently definite or useful definition of words and concepts. Bridgman emphasizes this in connection with his discussion of "Meaningless Questions."

In some cases questions fail to have meaning because of the more or less inherent fuzziness of the concepts involved. For example, if we compare two trees of about the same size it may have no meaning to ask which tree has the larger diameter, for no one has defined the diameter of a tree with the necessary precision.

A more important class of meaningless questions arises when there are no conceivable operations that could be performed to arrive at a decision. For example, what is the meaning of the question, "Would the United States have entered the World War if the *Lusitania* had not been sunk?" Such a question may be a good subject for a school debating society, but no one is apt to think that the question has thereby been answered.

A study of meaningless questions may serve a very useful purpose in science. A statement that a certain question has no meaning may be equivalent to stating a fundamental law of nature; for example, to say that the question, "What is the true velocity of the north star through space?" has no meaning is a fairly good statement of at least a part of the relativity theory.

In some cases it may have no meaning to ask whether or not there is a magnetic field in a certain portion of space. For example, suppose an observer, stationary on the earth, studies an electron in motion. The motion of an electron constitutes an electric current and experimentally he will observe the characteristic magnetic field surrounding this electron corresponding to this current. If another observer moves along with the electron, it will appear to him to be at rest, and, of course, he can observe no magnetic field. Otherwise the presence or absence of a magnetic field around an electron or group of electrons could be used to determine absolute motion through space, which would be contrary to the relativity theory. The relativity theory thus requires that a magnetic field can have no real existence in any absolute sense.

We have seen that there are fundamentally as many different concepts of length as there are different ways in which length may be measured; nevertheless, we find approximate agreement between different ways of measuring the diameter of molecules and therefore are justified in assigning some *reality* to the concept diameter of molecule. When, however, we ask what is the diameter of an electron, we find that the question is practically without meaning. It is true that we can calculate a diameter by assuming that the electron behaves like a charged sphere and that the classical laws of electrodynamics can be applied in this case. However, since we have no independent way of measuring this diameter, the process is one which involves reasoning in a circle.

There are many meaningless questions which afflict the chemist. It clearly has no meaning to ask what is the molecular weight of sodium chloride in a crystal. It is very doubtful whether it has any meaning to ask what is the molecular weight of water in liquid water. There are many cases where the concept of temperature has no definite meaning. Strictly speaking, temperature acquires meaning in terms of operations only in so far as an approach is made to equilibrium conditions. When the motions of molecules or atoms follow Maxwell's Distribution Law, *i.e.*, a random or probability distribution of velocity among the molecules, the concept of temperature becomes very definite. If, however, we deal with mercury vapor streaming into a high vacuum, or the conditions near a hot tungsten filament in a gas of low pressure, temperature has very little meaning. The same is true of the conditions frequently existing in an electric discharge tube such as a mercury arc, where the electrons act as though they had a temperature of perhaps 50,000 deg., whereas the atoms have motions corresponding to far lower temperatures. Strictly speaking, neither the electrons nor atoms have well-defined temperatures, for the conditions are far removed from equilibrium.

In much of the recent discussion of the Radiation Hypothesis of chemical reactions, chemists have been discussing meaningless questions usually without realizing it. At first it was proposed that the radiation is absorbed by the reacting gas to form excited molecules in accordance with Einstein's photochemical law. When this is found not to be in accord with experiment, the concept of radiation is altered repeatedly as new experimental facts are found so as to make the modified theory continue to fit the facts. After this process has been carried on sufficiently, it no longer has any meaning to ask whether the reaction is caused by radiation or whether the radiation hypothesis is true.

In the studies of the properties of liquids, questions of the degree of ionization and of association and in some cases of internal pressures have been discussions of questions without meaning. A great deal of such discussion might be simplified or even avoided entirely if chemists would agree in defining these concepts in terms of operations.

Theories of valence within recent years have been afflicted with the same difficulties. As long as chemists deal with the ordinary valence rules of organic chemistry, they are dealing with concepts of valence which are actually defined in terms of operations; *i.e.*, the organic chemists know how to conduct experiments to prove that the valence of nitrogen in dimethylaniline is 3. The types of operations needed to establish the valence of magnesium in magnesium chloride are in many ways quite different, and they are still different if we consider the case of so-called quinquevalent nitrogen in ammonium chloride or heptavalent chlorine in perchloric acid. I believe that the chemist has much to learn from the physicist in regard to the proper method of attacking such problems as these.

The electrochemist has been troubled in locating the source of electromotive force in cells. The physicist has similar difficulty in finding the origin of the contact potential between metals. Fundamentally it must be recognized that unless or until there are methods by which these quantities can be measured, questions involving them have no meaning.

A practical example of the meaninglessness of some questions involving electric potential has recently arisen in the numerous proposals that have been made to construct a speed indicator for airplanes which will give the speed with respect to the earth's surface independently of that of the wind surrounding the plane. It is reasoned that since the plane is moving through the earth's magnetic field a potential will be set up between the ends of a wire stretched between the wing's tips. It is only necessary to measure this potential difference in order to calculate the speed of the plane with respect to the earth. Careful analysis shows that the concept of the potential difference under these conditions is meaningless except with reference to a particular reference system. If this system is referred to the plane itself, this potential difference is zero quite regardless of what the speed of the plane may be with reference to the earth. A contrary result would conflict with the relativity theory.

Meaningless questions will assume far greater importance in future years. We shall see that the latest forms of the quantum theory now give us the best of reasons for believing that the identity of separate electrons within atoms or molecules may be partly or wholly lost, so that it may have no meaning to ask whether a particular electron we find as a result of experiment is the same electron which has previously produced an observed phenomenon. Even more far-reaching in its consequences is the Bohr-Heisenberg Uncertainty Principle according to which it has no meaning to ask what is the precise position and velocity of an electron or atom. An electron may have a definite position or a definite velocity but it cannot in any exact sense have both. This doesn't mean merely that there are experimental difficulties in measuring them, it means that the concepts themselves (position and velocity) are relative to one another in a sense somewhat analogous to that of time and space in the relativity theory.

One's instinctive reaction when first questioned as to the objective reality of space, time, position, velocity, etc., is to object to such consideration on the grounds that they are too metaphysical. The recent advances in physics demonstrate that these methods of thinking are eminently practical; they represent, in fact, an attempt to get away from the metaphysical character of much of our thinking in the past. Instead of taking for granted objective realities corresponding to our concepts, we now deal with things which can be measured in the laboratory, the concrete data from which we have to start.

It is, however, very useful to retain the concept of reality. Bridgman suggests that reality should be measured by the number and the accuracy of the independent ways in which we arrive at similar measures of the concept in question. For example, owing to the fact that we have so many concordant methods of measuring the distance between the ends of a base line used for triangulation, we attribute great reality to the concept of length or, rather, to those concepts of length which are applicable in cases of this kind. We thus have some justification in saying that two points are really one kilometer apart. We do not attribute, however, much reality to the concept of the diameter of an electron.

Thirty years ago the physical chemist doubted the existence of atoms or believed the concept was useless if not pernicious. A few years later the leader of this movement, Ostwald, in the preface of one of his books stated that he believed that the existence of atoms had been proved experimentally beyond question, although in previous books he had stated that there are always an infinite number of hypotheses that could be advanced to explain any given set of experimental facts.

Today, what can we say in answer to the question, "Does matter really consist of atoms?" Must we say that this is one of those meaningless questions?

Of course, the amount of meaning that can be attached to any such question depends upon the definitions of the words and concepts which it contains. If we mean by atoms indivisible and indestructible infinitely hard, elastic spheres, we are compelled to answer the question in the negative. In accordance with modern usage, however we do not attribute any such properties to the atom. If, by the use of the word atom, we mean to imply principally the concept that matter consists of discrete particles which can be counted by the various methods which are now known for this purpose, we have the very best of reasons for answering the question in the affirmative. If in our studies of nature we discover evidences of discontinuities or of the presence of discrete natural units which can be correlated in a definite way with the numerical integers, we have come, it would seem, about as close to something absolute in nature as we can hope to get. Einstein in the relativity theory has taught us to look upon the intersections of world lines as the data upon which our observations of nature rest. Such points of intersections, which can be called events, are essentially discontinuities. In general, they are all unlike one another. When we find in nature discrete units which in many respects appear to be identical with one another, and we can count these units, it would seem that the number of these units which obtain as a result is apt to be independent of our system of reference; therefore, they have in general, a certain kind of absolute significance.

In this respect, therefore, it seems that the atomic theory and the quantum theory in which integers play such a fundamental rôle may be considered as representing reality to a higher degree than almost any other of our physical and chemical theories.

Skepticism in regard to an absolute meaning of words, concepts, models or mathematical theories should not prevent us from using all these abstractions in describing natural phenomena. The progress of physical chemistry was probably set back many years by the failure of the chemists to take full advantage of the atomic theory in describing the phenomena that they observed. The rejection of the atomic theory for this purpose was, I believe, based primarily upon a mistaken attempt to describe nature in some absolute manner. That is, it was thought that such concepts as energy, entropy, temperature, chemical potential, etc., represented something far more nearly absolute in character than the concept of atoms and molecules, so that nature should preferably be described in terms of the former rather than the latter. We must now recognize, however, that all of these concepts are human inventions and have no absolute independent existence in nature. Our choice, therefore, cannot lie between fact and hypothesis, but only between two concepts (or between two models) which enable us to give a better or worse description of natural phenomena. By better or worse we mean, approximately, simpler or more complicated, more or less convenient, more or less general. If we compare Ostwald's attempts to teach chemistry without the use of the atomic theory with a good modern course based upon the atomic theory, we get an understanding of what should be meant by better or worse.

The more recent advances in atomic theory which have resulted from the development of the quantum theory and which have given us our present knowledge of atomic structure, afford us interesting applications of the new methods of thought, first introduced into physics and chemistry by the relativity theory.

The older atomic and molecular theories of the chemists took on more definite form through the development of the kinetic theory of gases, and through the electron theory and the study of radioactivity developed to a point where the atom is conceived of as consisting of a definite number of electrons revolving around the nucleus. The atom ceased to be indestructible and was no longer the smallest particle of matter which could take part in a chemical reaction. The nucleus, rather than the atom, became characteristic of the chemical elements. The chemical properties of the atom, however, depended upon the number and arrangement of electrons.

Bohr, in 1913, developed a marvellous new theory of the atom by combining Planck's quantum theory with a relative theory of the nuclear atom. He evolved several new quantitative mathematical relationships with new concepts such as energy levels, quantum states, etc., and showed how the spectra of elements could be explained in terms of these new concepts. He also gave a mechanical model consisting of electrons revolving in orbits about the nucleus according to laws which were partly classical and partly inconsistent with classical laws. This model enabled him to derive certain mathematical equations from which he was able to calculate the frequencies corresponding to the different lines in the spectra of hydrogen and other elements, these frequencies being obtained from fundamental quantities such as the charge and mass of the electron and the quantum constant h, and did not involve any quantities dependent on the properties of the elements in question. The agreement between the theory and experiment was practically perfect, often enabling the frequency to be calculated with an accuracy of one part in two hundred thousand.

Such remarkable success made most physicists and chemists believe that Bohr's model, for the hydrogen atom at least, was substantially correct. That is, they believed that Bohr's work proved that in a normal hydrogen atom the electron really described a circular orbit around a nucleus having a diameter and a frequency given by Bohr's model. Bohr himself never attached any such importance to the mechanical model, realizing that the important steps that he had taken consisted mainly in the introduction of new concepts and more particularly in the mathematical equations by which the observed frequencies in the spectral lines could be calculated.

Within recent years, largely through the work of Bohr himself and his students, and Sommerfeld, Schroedinger, and others, this theory of the hydrogen atom has undergone changes. According to Bohr's original model the radiation of energy corresponding to a spectral line resulted from transition in which the electron passed from one stationary orbit to another. No physical picture of this transition seemed possible. To account for the known phenomena it seemed necessary that the transition should occur so rapidly that the electron would have to move from one orbit to another with a velocity greater than that of light, and yet the train of waves in the resulting radiation lasted for relatively long periods of time, about 10^{-8} seconds. Radiant energy could be absorbed by the atom only if the frequency was just that which was capable of transferring an electron from one orbit to another definite orbit. Thus only one frequency could be absorbed at a time by an atom. It was found, however, that the frequencies corresponding to many lines could be scattered by a single atom. This seemed to require the presence within any given atom of a number of oscillators as great as the number of lines in the spectrum. One of the greatest arguments in favor of the original Bohr theory was that it avoided just this sort of complication in the atom.

To get rid of difficulties such as these, Heisenberg and Born realized that it was necessary to sweep out of the theories of atomic structure the many concepts which were characteristic of the mechanical models that had been proposed and to develop a mathematical theory of the atom which would involve only concepts that were definable in terms of operations. That is, the theory was one that dealt more directly with measurable quantities such as the frequencies of spectral lines. New methods of matrix calculus had to be evolved, a kind of calculus of discontinuities or discrete quantities instead of the calculus of continuous quantities which had characterized classical mechanics.

Only a little later, Schroedinger, by developing DeBroglie's wave theory of quantum phenomena, was able to build up a theory that we will now refer to as the wave mechanics, according to which the whole atom with all its electrons can be looked upon as a wave phenomena. The electrons are no longer considered to be moving in orbits. For example, the hydrogen atom is found to have spherical symmetry instead of the axial symmetry of the old Bohr model of the atom. Yet this theory leads to identically the same equations for the frequencies of the lines in the hydrogen spectrum. We must not say that Bohr's theory of the hydrogen atom has been overthrown. Bohr's *mechanical* model has been superseded, but the more important model which is represented by the equations and the concepts which he evolved is even better today than it was when it was first proposed.

The wave mechanics which involves the calculus of continuous variables is not now in conflict with the Born matrix calculus of discrete quantities. The two theories are essentially merely different mathematical methods applied to a single fundamental problem. The resulting mathematical equations always agree with one another. One begins to believe that the mathematical theory is a far better model of the atom than any of the mechanical models which are possible.

The long-standing conflict between the wave theory of light and the corpuscular quantum theory now disappears with the new wave mechanics, the two aspects of light being somewhat analogous to the two aspects of the quantum theory, the wave mechanics and the matrix mechanics. In fact, the quantum theory now indicates that the electron itself can be regarded as a particle, or as a wave, just as light can be thought of as a photon or a wave. Whatever remained of the conflict between the wave and corpuscular theory of light and of the electron seems now to be fundamentally removed by the Bohr-Heisenberg Uncertainty Principle. To ask whether an electron is a particle or a wave is a meaningless question; the same is true of the question whether light consists of corpuscles or waves. One must answer that both of these are particles or waves according to the kind of operations that we may perform in observing them. If we make an experiment which proves that an electron has a very definite position, then it would seem to prove that it is a particle. In that case, however, according to the Uncertainty Principle, we are not able to determine accurately the velocity and therefore cannot predict where the particle will go.

Bohr has emphasized that the essential reason that the classical theory falls down in any detailed description of atomic phenomena is that our knowledge of such atomic systems can be obtained only through an act of observation which makes the observer inherently a part of the system. On the classical theory we assume that we could have knowledge of a completely closed system as though it were possible to know anything of what would go on in a strictly closed system. In order to make an observation some signal must be transmitted from the system to ourselves, and if we take this interaction completely into account we are forced to the quantum theory with its Uncertainty Principle.

An interesting feature of this new quantum mechanics is that the original conception of the relation between cause and effect which was universally accepted in science has lost its meaning. Atomic processes seem to be governed fundamentally by the law of probability. It has no meaning to ask when a particular radium atom will disintegrate, for no operation is conceivable by which such an event could be predicted. The same is true of every individual quantum process. We have no guarantee whatever that the expulsion of an α-particle from an atom of radium has any immediate cause. In chemistry the formation of nuclei in supercooled liquids, etc., must be essentially quantum phenomena in which no cause can be assigned for the formation of the individual nucleus. By varying the conditions we may alter the probability that a nucleus will appear at a given point, but in no absolute sense can we ever make a nucleus form through a direct cause.

By a deeper analysis of this question of causality, Bohr concludes that we have an option of two alternative descriptions of natural phenomena. If we choose to describe phenomena in terms of ordinary space and time then we must abandon causality. We may, however, retain the conception of causality if we are willing to describe atomic phenomena in terms of what the mathematician calls configuration space. Consider, for example, a helium atom with its two electrons. If we attempt to give the position of both of these electrons in space we would need a set of three coördinates, x, y, z, for each of the electrons, that is, six coördinates in all, three of which belong to one and three to the other electron. The mathematician, however, finds that the two electrons in general could also be described by one point in six-dimensional space, for such a point has six coördinates. This is a representation of two electrons as a single point in a configuration space of six dimensions. Now it turns out from Schroedinger's theory that the motion of electrons, or rather of the waves corresponding to them, can be completely described in the case of the helium atom by a quantity which has a particular value at each point in this six-dimensional space or configuration space. The helium atom, however, can be described in terms of the motion of two electrons in three-dimensional space if we are content merely to know the probabilities that the electrons may be found at any point in this space.

These matters undoubtedly seem very abstract to those of you who have not previously become familiar with them. I give them here mainly in order to illustrate how far the modern concepts of physics differ from those of twenty years ago.

If we must thus abandon our ordinary ideas of cause and effect, it may be asked why have the physicist and chemist so long believed that the whole teaching of science gave proof that every phenomenon resulted inevitably from the causes that led to it. I think the answer is that in the past scientists chose as the subjects for their investigations almost wholly those phenomena in which such definite relations as cause and effect could be found. These phenomena are those in which such enormous numbers of individual quantum phenomena are grouped together that the result is determined only by their averages. For example, when we study the variation of the pressure with the volume of a gas, the forces that we measure result from the impacts of great numbers of molecules, the average force remaining steady and definite. If, however, we only had one molecule in a small volume, the pressure exerted on the walls would be zero except for those instants at which the molecules struck the wall. It would then be impossible to predict in advance what the pressure would be at a particular time.

I think in trying to estimate the reliability of any of our scientific knowledge we should keep in mind that the whole complexion of a science may be made to change by the psychology of the investigators which governs the choice of the subjects that are investigated.

Our best knowledge of time and its relation to other concepts is that which we have obtained through Einstein. Yet in the whole relativity theory there is nothing to distinguish between positive and negative time, *i.e.*, between future and past, any more than there is between different directions in space, such as right and left. There thus appears to be something curiously incomplete in our knowledge of time, for every one of us knows the vast practical difference between past and future. Eddington, in his recent book, *The Nature of the Physical World*, discusses the "arrow of time" at some length. He suggests that the second law of thermodynamics is the only fundamental law of nature which provides us with any distinction between future and past. One way of stating this law is that all spontaneous processes that occur in nature involve an increase in entropy. Eddington thus proposes that the positive direction of time can be defined as that direction in which the entropy increases. If we had a system in absolute equilibrium the entropy would be constant, and there would then be no arrow of time. This is in accord with the fact that in such a system there are no changes with time.

It is improbable that there are two independent fundamental factors which provide an arrow for time, so that it would seem that Eddington in having found one such factor has found the only one. There are, however, grave difficulties with this view. An arrow is a vector quantity which should have magnitude as well as direction. Now the rate of change of entropy does not seem to give us any measure of time. For this purpose we use phenomena which are as nearly reversible as possible, such as the swinging of a pendulum in a vacuum.

Fundamentally entropy is a measure of randomness. A random distribution of molecules in space and velocity is a system having the maximum entropy. If we throw a pack of cards out of the window and collect them from the ground they have become effectively shuffled. We would not expect by this process, starting with a shuffled pack of cards, to find them at the end in the order in which they came from the manufacturer. The direction in which the randomness increases thus provides an arrow for time. This arrow is, however, equivalent to that involving the increase of entropy.

It is still an open question, however, whether processes directed by intelligent beings may not involve a decrease in entropy. In fact it seems conceivable that the evolution of organic life on the earth is in some measure fundamentally contrary to the second law of thermodynamics. The inherent tendency of evolution seems to be to bring about an ordered rather than a random arrangement of parts, and in the future perhaps forms of life may evolve which cause a decrease of entropy on a large scale. Are we then to have some parts of the universe in which the arrow of time points in the opposite direction from that in neighboring parts?

Such speculations may seem fantastic. It is, however, I believe, of the utmost importance for the chemists and the physicists to evolve fundamentally sound conceptions of such things as time and entropy.

The profound changes in physical thought, particularly those represented by the Quantum Theory, are rapidly bringing about a revolution in physical chemistry. The third law of thermodynamics involving chemical constants has changed radically our methods of studying chemical equilibria. The application of the Quantum Theory to band spectra promises to be of the utmost importance in chemistry. By enabling us to determine the moments of inertia of chemical molecules the actual distances between the nuclei of the atoms in molecules can be found. Apparently our most accurate determinations of the heats of dissociation of elementary gases can be obtained from the band spectra through a knowledge of the energy levels of the various possible states of the molecules. In recent numbers of the *Journal of the American Chemical Society*, particularly in the paper of Giauque and Johnston, we see the beginnings of what promises to be the most accurate and fertile source of knowledge of chemical equilibria. From a detailed knowledge of the spectrum, for example, of oxygen, and without recourse to any other experimental determinations, the specific heat at all temperatures can be calculated, and the entropy of oxygen at all temperatures is thus found. This, together with the heats of reactions, which may be found by a similar method, makes possible the calculation of the degree of dissociation of oxygen and will ultimately make possible the calculation of all chemical equilibria.

The remarkable work of Dennison, Bonhoeffer, and Eucken in predicting and isolating para-hydrogen should prove to the chemist how many of his chemical discoveries will be obtained in the future by the application of these new theories of physics.

Gurney and Condon have recently derived from the wave mechanics an explanation of the fundamental law of radioactivity. Similar methods will probably before long enable us to understand the processes involved in chemical reactions far better than we ever have before.

Physics and chemistry are being inevitably drawn closer together. It seems that there has never been a time when we can predict with such certainty rapid progress in fundamental chemistry, for the new theories of physics have as yet scarcely begun to be applied in the field of chemistry. The physicist on the other hand has much to learn from an increased knowledge of chemical phenomena which should provide him with a richness of experimental data far greater than any he has yet had an opportunity to use.

Unfortunately, although theoretical physics and chemistry are thus supplementing each other and in many respects are being merged into a new science, there are remarkably few men as yet that have received adequate training in both sciences. Before long, I hope, sharp distinctions between physics and chemistry will no longer exist, but at present there seems to be a very practical distinction.

In order to find approximately how many chemists are also active as physicists and *vice versa*, I have selected at random 100 pages of the fourth edition of *American Men of Science* (1927) which contains the names of 13,500 American scientists. Of these, approximately 2700 are classed as chemists and 760 as physicists. Of the chemists 87 per cent are members of the American Chemical Society, while only 2.5 per cent belong also to the American Physical Society. Seventy-seven per cent of the physicists are members of the American Physical Society, while 3.3 per cent are also members of the American Chemical Society. Thus only about three per cent of the physicists and chemists of the United States, whose names are given in the *American Men of Science*, belong to both of the national societies. This leaves far too small a number of men who are capable or are properly prepared to carry on the important work of bringing these two sciences closer together.

To pave the way for the coming revolutionary changes in chemistry we must be prepared to modify our methods of thinking, probably along lines now so prevalent in physics. But above all we must urge young chemists in the universities and after graduation to become thoroughly well trained in mathematics and in modern physics.

Glyptal Lacquers

By **LAWRENCE E. BARRINGER**
Engineer of Insulations, General Electric Company

NOT long ago, phthalic anhydride was a chemical rarity, produced from naphthalene, and quoted at five dollars a pound. Today it is an important heavy organic chemical used in the manufacture of dyestuffs and selling at less than 20 cents a pound. This chemical has been combined with glycerine, a by-product of the soap industry, to produce a synthetic resin. Although compounds of glycerine and resin-forming acids had been studied by chemists during the latter half of the nineteenth century, no commercially useful compounds of this class had been made before the General Electric research laboratories developed alkyd resins. Various phthalic anhydride or alkyd resins are now being manufactured under the trade name "Glyptal."

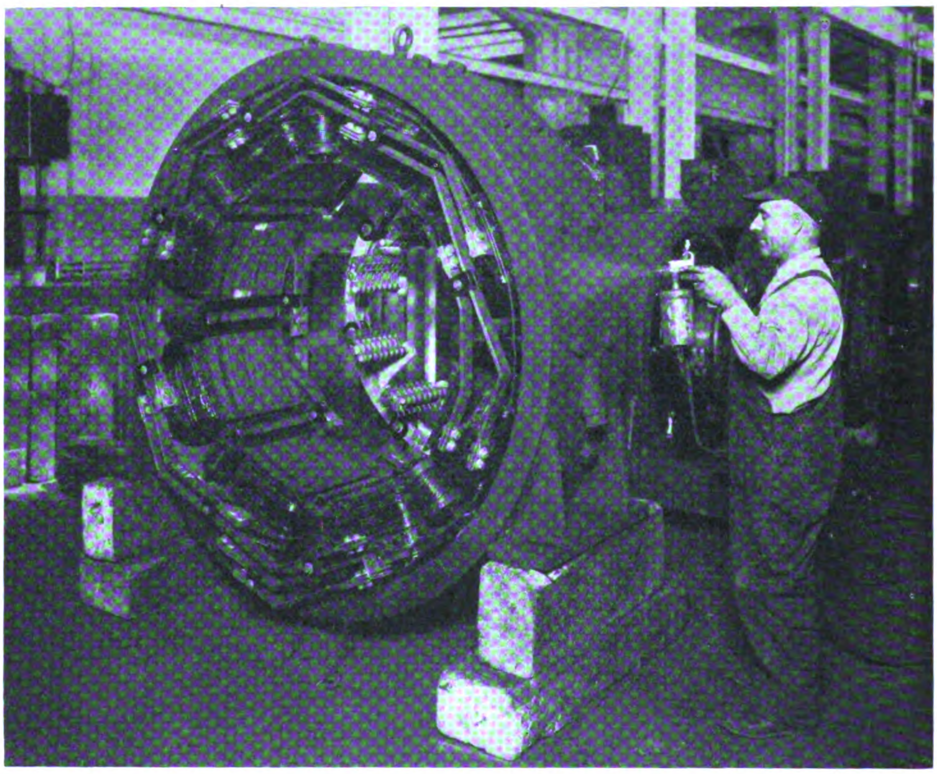

Fig. 1. Factory Application of Glyptal Lacquer on the Frame of a D-c. Machine

Glyptal in modified forms is finding many uses.(1) In its flexible form its most important function is as the base of finishing and protecting materials such as paints, varnishes, lacquers, etc.

A detailed description of the study and tests which ultimately led to the development of Glyptal lacquers will not be attempted at this time. Consideration will be given only to the qualities which intensive research proved to be inherent in these remarkable coverings.

Glyptal lacquers are resistant to all mineral oils, and, when baked, to their fractions—gasoline, kerosene, etc. They also resist weak acids and alkalies. They withstand temperatures in excess of 600 deg. F. and have a higher dielectric strength than many commonly used paints.

They are superior as finishing coatings for any surface; and are particularly suitable for covering surfaces that are ordinarily difficult to coat, such as aluminum and galvanized iron, because tenacious adhesion is one of their outstanding properties. The finish which they produce is smooth, easily cleaned, and durable because it is unusually resistant to abrasion.

Up to the present time they have been produced in the following colors: aluminum, blue, brown, green, gray, black, and red.

Methods of Application

All the Glyptal lacquers have basically the same general characteristics and may be applied by spraying, brushing, or dipping. They air-dry, dust-free in 30 min., may be handled in 2 hr., and set hard in 8 to 10 hr. The drying time is greatly accelerated by heat. Baking improves the coatings and somewhat prolongs their good qualities where this treatment is convenient.

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(1) A number of these uses, particularly that as a cement in built-up mica insulation, were described in the articles, "A Revolutionary Development in Mica Insulation," by L. E. Barringer, Nov., 1926, p. 757, and "Glyptal Mica Moves Ahead—Now the Flexible Form," Oct., 1929, p. 530, both in the GENERAL ELECTRIC REVIEW.

Uses

Because of the hundreds of uses for Glyptal lacquers, it would be impractical to give more than a few specific examples, but the following will at least indicate the wide scope of their possible application.

The aluminum Glyptal lacquer is particularly resistant to heat. In fact, tests show that temperatures as high as 600 deg. F. produce practically no discoloration in the finish, for which reason it will prove unusually serviceable as a coating for metal parts that are exposed to high temperatures (as furnace stacks, electric furnace parts, radiators, gasoline engine parts, steam boilers, etc.). It nevertheless possesses all the good qualities of the other Glyptal lacquers for uses at ordinary temperatures, and in addition has better light-reflecting characteristics which make it doubly valuable in poorly illuminated surroundings.

The red lacquer should be given first consideration wherever a sealing or protective paint of pleasing appearance and high dielectric strength is required. In addition to adhering strongly to metal and protecting it against rusting, it finds many applications also as an unexcelled seal against oil, gas, and water leaks.

In the electrical field of applications, the red lacquer finds effective use in connection with the manufacture and maintenance of both direct-current and alternating-current apparatus and also of storage-battery equipment. For motors of either the d-c. or a-c. type, it will seal the housings against the entrance of dust and the leakage of oil. The motors so treated will thus require less frequent oiling, their bearings will be less likely to run dry through leakage, and the motor maintenance costs will be substantially reduced. The ends of commutators and also the surface between the ends of the commutator bars and the cone may be advantageously protected against the entrance of oil, moisture, carbon dust, and copper dust by a coating of the same lacquer. For those d-c. motors which in mine-pumping operations are exposed to considerable oil and moisture, this red lacquer will afford additional service as a protective coating on the shunt, series, and interpole field coils. It is equally desirable for painting the field coils of mine-locomotive motors. The terminals and immediate surroundings of storage batteries have been notoriously difficult to maintain in a cleanly condition and free from corrosion. An effective remedy lies in applying the red lacquer to the battery box and container, and to the tops of the cells and terminals.

In electric railway work, the red type of Glyptal lacquer has been used to protect motor insulation and exposed metal parts. In steam railroading, the same lacquer has been made use of to seal the many piping systems employed. It has also found use in quantity for painting the under-roofs of terminals and roundhouses, and structural iron subjected to carbon dioxide and sulphurous fumes. Its smooth surface minimizes the collection of surface dirt and makes it easy to clean.

The foregoing properties of the red lacquer, together with its dielectric value, open up many uses for it in power houses and in the allied distribution system equipment. Oil switch tanks furnish a desirable application. Then, again, its sealing properties find valuable use in making up oil pipe joints. As in the case of motor windings, it furnishes a protective coating for the insulation of generators. On exposed busbars and other live parts, its color will serve as a warning of danger.

In the oil refining and distributing industry, the lacquer of red color is an important accessory. Here, it is used to paint the inside of storage tanks and ships, to seal pipe lines and tank cars, and to protect electric motors subject to oil fumes and moisture.

A great many uses have been found in other industries for the red Glyptal lacquer. It has been successfully applied in hundreds of places where a sealing paint to resist oil, gas, moisture, and mild acids was required. Many manufacturers of such products as oil burners, and others requiring tight joints and seams to contain oil, gases, and acids, have effected manufacturing economies and helped to reduce the need of servicing by adopting this lacquer.

Gas companies can make use of it to protect and seal gas tanks, gas mains, meters, and household piping.

In ships and shipyards, oil, water, and refrigeration lines may be tightly sealed with the lacquer. It has an important application also in the protection of motors and metal parts of ships which are exposed to oil or to corrosive vapors.

The blue, brown, green, gray, and black Glyptal lacquers are intended primarily for finishing purposes, although they may also be used for many of the same applications for which the red lacquer is most suitable. As coatings for manufactured articles, especially those of metal, experience has shown that they afford worthwhile economies. Where fine finishes are desired on rough surfaces, and it has been the practice to prime, fill, sand, size, and paint the surfaces, the substitution of any of these Glyptal lacquers for the paint makes the operations of priming and sizing unnecessary.

All the foregoing lacquers were developed in the research laboratories of the General Electric Company and have successfully passed rigid tests in the factories of the Company and in the field.

Ultra-violet Radiation from the Sun and from Heated Tungsten

Review of Studies of Radiation from Tungsten—Recent Calculations of the Ultra-violet Component—Measurements of Ultra-violet Radiation from the Sun—Minimum Values Would be Exceeded by Corresponding Radiation from Quartz-bulb Tungsten Lamp

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THE amount of ultra-violet radiation from various sources, including tungsten, has been discussed many times.(1) The radiation from a tungsten filament at a high temperature, no doubt, extends to very short wave-lengths. Although the intensity of this radiation except at very high temperatures is small, the data given herein indicate that it is not so small as has been generally supposed in the past.

> *With change in season, time of day, latitude, and clearness of the atmosphere, the ultra-violet radiation received from the sun varies from more than enough for human comfort to less than is desirable. The comparative data given in this article indicate that a suitable tungsten lamp radiates sufficient ultra-violet energy to make additional investigation of the subject worth while.*—EDITOR

The spectrum of the total energy radiated by a hot body may be divided into three portions for discussion: the infra-red, which is generally considered to extend from about 0.76μ to longer wavelengths; the visible spectrum, which extends from 0.40μ to 0.76μ; and the ultra-violet, which extends from 0.40μ to shorter wavelengths. The ultra-violet is sometimes separated into the near ultra-violet extending from 0.40μ to 0.30μ and the far ultra-violet extending from 0.30μ to shorter wavelengths.

Weinger and Pfund(2) made a study of the infra-red radiation of tungsten, extending their work to wavelengths of about 4μ. They showed that for wavelengths longer than about 2μ the spectral emissivity e_λ could be calculated for different temperatures by means of Drude's formula

$$100-R_\lambda=e_\lambda=3650\sqrt{\rho/\lambda}$$

where ρ is the specific resistance for the temperature considered, R_λ the reflectivity, and λ the wavelength in μ. Making use of this relation the emissivity of heated tungsten can be calculated for longer wavelengths and for higher temperatures than they extended their measurements. Several investigations(3) have been made in the laboratory at Nela Park on the visible radiation of tungsten with the result that the distribution of energy in this part of the spectrum is quite well known. Hulburt(4) working in this laboratory, made a study of the ultra-violet radiation from tungsten, extending his work to wavelengths of about 0.34μ and to temperatures of about 2800 deg. K. From these measurements he calculated the emissivity of tungsten for the ultra-violet part as far down as the wave-length 0.34μ. The final values that he obtained, corrected to the present temperature scale of tungsten, are reproduced in Fig. 1. His test points are shown and the curves have been extrapolated to 3400 deg. K. From the curves it seems that these extrapolated values cannot be in error by as much as five per cent. We are interested, however, in knowing the radiation down to 0.30μ, and if possible down to about 0.28 or 0.29μ, since it is radiation of wavelengths in the neighborhood of 0.30μ that are the so-called "vital rays," *i.e.*, the rays that are supposed to be effective in promoting health and growth in plants and animals.

One method of calculating the energy distribution in the visible portion of the tungsten spectrum is by making use of the color temperature of tungsten, which has been determined for quite a range of temperatures.(5) By color temperature is meant the temperature at which it is necessary to operate a black body so that the emitted light from the black body will be of the same color as that of the source under investigation. For instance, it was found that the light from a tungsten lamp operated at a temperature of 2400 deg. K. has the same color as the light from a black body at 2450 deg. K. From this the color temperature of tungsten corresponding to a true temperature of 2400 deg. K. is 2450 deg. K. Color temperature thus defined and measured refers to the visible spectrum and not to the infra-red or ultra-violet parts of the spectrum.

By extended tests it has been shown(6) that when a tungsten filament and a black body are color matched they have the same spectral distribution to within about one per cent throughout the visible spectrum. The spectral distribution of energy from hot tungsten varies from that of a black body at color match in such a manner that if these two radiators are set so as to have the same ratio of red brightness to blue brightness, the radiation from the tungsten in the green portion of the spectrum will be relatively brighter than that from the black body. If this same relation holds for shorter wavelengths, measured values of emissivity should be smaller than values calculated from color temperature relations. Such calculations have been made for wavelength 0.34μ and for a color temperature of 2800 deg. K. The calculations gave 0.495 as the emissivity, while Hulburt's test value for this same temperature is 0.485. This shows that Hulburt's measured value of emissivity for this region is in general agreement with the work in the visible spectrum.

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(1) Coblentz, *Trans. I.E.S.*, *23*, p. 247 and 1121, 1928.
Luckiesh, M., *Jour. Frank. Inst.*, *206*, p. 57, 1928.

(2) *Phys. Rev.*, *14*, p. 427, 1919.

(3) *Phys. Rev.*, *10*, p. 397, 1917.
J.O.S.A. *7*, p. 1115, 1923.
Phys. Rev., *10*, p. 377, 1917.

(4) *Astrophys. Jour.*, *45*, p. 149, 1917.

(5) *Astrophys. Jour.*, *61*, p. 176, 1925.

(6) *J.O.S.A.*, *7*, p. 1115, 1923.

Making use of all the foregoing relations and data, the emissivity of tungsten for a temperature of 2800 deg. K. and for a range of wavelengths from 0.34 to 4μ has been calculated, and the results plotted in Fig. 2. As shown, this curve has been extrapolated to 0.27μ. Similar curves have been plotted for other temperatures where the values for the shorter wavelengths have been obtained by cross-extrapolation where necessary. These extrapolations assume, of course, that there is no sudden change in the radiation characteristics of tungsten. Practically all metals become poor reflectors, *i.e.*, good radiators, for short wavelengths. The curve for tungsten shows a trend in that direction. Quite likely any change would be toward a smaller value for the reflectivity rather than in the opposite direction. It is therefore thought that the values of emissivity given for the far ultra-violet are, if in error, smaller than the true values. Work is now under way in this laboratory to check these values by actual measurements in the ultra-violet region.

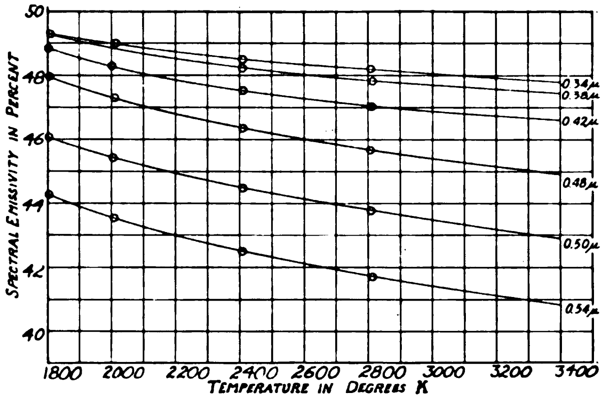

Fig. 1. Spectral Emissivity of Tungsten for Different Temperatures and Several Different Wavelengths

O—Hulburt's experimental values

From values of emissivity thus obtained, the spectral distribution of energy radiated by tungsten lamps at different temperatures has been calculated for a range of wavelengths from the very short ultra-violet to the long infra-red. By step-by-step integration the relative amount of energy in the various portions of the spectrum of tungsten at different temperatures has been calculated and is shown in Table I. From these relative values and the total wattage of the lamps, the amount of energy in the different wavelength intervals falling upon a square centimeter at a distance of one meter from the different lamps was calculated and is also shown in Table I.

There are not many data available concerning just how much ultra-violet radiation or just what wavelength limits are necessary to produce desired therapeutic effects. Maughan in a recent paper(7) reviewed this subject and gave some very interesting data on wavelength limits necessary to cure rickets in chickens. This author showed that the mercury line 0.296μ is much more potent for this effect than 0.312μ, which is more intense. According to this work, wavelength limits longer than 0.3012μ have very little, if any, value in curing rickets in chickens. It is generally stated that common window glass is practically opaque to the so-called "vital rays." The short-wavelength transmission limit of window glass varies with the particular glass considered, but very little is transmitted below 0.31μ. Maughan showed(7) that irradiating the chickens with a mercury arc through window glass for about 22 min. a day had no curative effect for rickets.

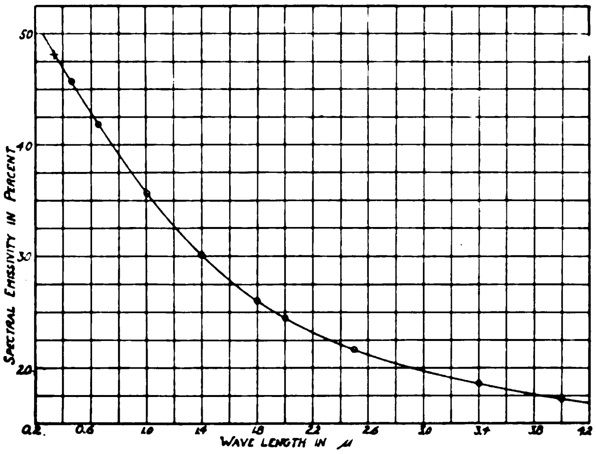

Fig. 2. Spectral Emissivity of Tungsten for 2800 Deg. K.

O—Weniger and Pfund's values
●—Worthing's values
X—Hulburt's value

From a consideration of the preceding it was decided to choose two wavelength limits for the so-called "vital" ultra-violet energy in these calculations. The first limit was from 0.325μ to 0.29μ and the second from 0.31μ to 0.29μ. The long-wavelength limits may or may not be correct, but there is quite a definite reason for selecting 0.29μ as the shorter wavelength limit as will be shown later. Concerning the amount of ultra-violet energy necessary, it is generally agreed that the sun sends us a sufficient amount provided enough of the surface of the body is exposed for a long enough time. Of course, the additional precaution is generally stated that the exposure should not be at or near a great city, since the smoke and dust generally found in such places very greatly reduce, if they do not entirely absorb, this "vital" radiation.(8) In a good many regions of the earth at certain times of the day the sun's rays are entirely too intense to be endured if the body is directly exposed to these rays. The results in the report on window-glass substitutes $^{(9)}$ show that in the latitude of Boston during January and February there is enough ultra-violet energy from the sun to prevent rickets in chickens, but rickets is not prevented if the same sunlight is filtered through window glass. As a comparison, it was thought worthwhile to calculate the amount of ultra-violet energy from the sun in the so-called "vital" regions using the wavelength limits that have been given.

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(7) *Amer. Jour. Physiol.*, *87*, p. 381, December, 1928.
(8) Bundesen, Lemon, *et al.*, *Jour. Amer. Med. Assoc.*, *89*, p. 187, 1927.

The values used for the energy transmission of the atmosphere and the distribution of energy in the sun's spectrum outside the earth's atmosphere were the published values of Abbot $^{(10)}$ and his co-workers of the Smithsonian Institution, supplemented for very short wavelengths by the values published by Fabry and Buisson. $^{(11)}$ In Fig. 3 is shown the transmission of the atmosphere for the short-wavelength region that has been used in this calculation. These values were arrived at as a result of a comparison of all the available data. The actual values of the sun's spectral intensity in the ultra-violet region that were used were obtained by following the findings of Abbot, $^{(12)}$ who made an extended analysis concerning the distribution of energy in the ultra-violet portion of the sun's spectrum. Fabry and Buisson in their determination of the radiation in the ultra-violet portion of the sun's spectrum showed that the amount of energy that reaches the earth's surface for wavelength 0.29μ is only one-millionth that for wavelength 0.314μ; which shows that the energy for wavelength 0.29μ is extremely small because even at 0.314μ the intensity is small. The fact that the energy that reaches the earth's surface is practically zero for 0.29μ and shorter wavelengths is thought to be due to absorption in the upper atmosphere, probably by ozone in that region, since it is quite well known that the sun sends out considerable energy at these short wavelengths. The limit thus set for the sun's spectrum is taken as the lower limit of the so-called "vital rays." Whether rays of shorter wavelengths are of any great value or whether they cause harm is not definitely known. From the values of the transmission of the earth's atmosphere and the distribution of energy in

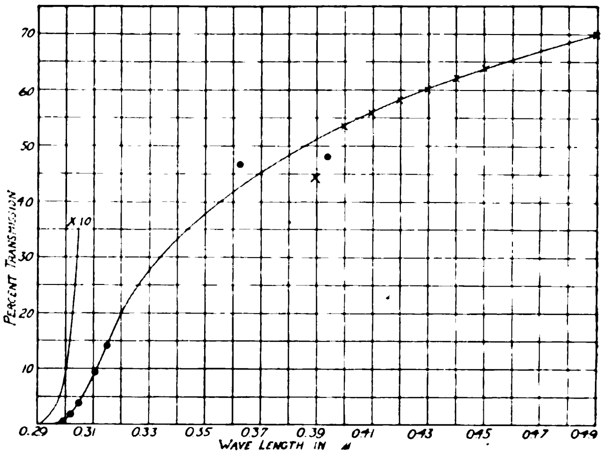

Fig. 3. Spectral Transmission of the Atmosphere for Short Wavelengths

●—Fabry and Buisson's values
X—Abbot's values
Curve marked X 10 same as main curve but plotted with the transmission multiplied by 10.

TABLE I

ENERGY IN VARIOUS PARTS OF THE SPECTRUM OF THE SUN FOR VARIOUS AIR MASSES AND FOR SOME TUNGSTEN LAMPS

Region	SUN(a)						2.37 ATMOSPHERE(d)	
	1 ATMOSPHERE		1.07 ATMOSPHERE(b)		1.5 ATMOSPHERE(c)			
	Per Cent	Milliwatts	Per Cent	Milliwatts	Per Cent	Milliwatts	Per Cent	Milliwatts
0.31—0.29μ	0.022	0.024	0.019	0.020	0.0063	0.0061	0.00051	0.00041
Below 0.325μ	0.24	0.26	0.21	0.22	0.11	0.11	0.029	0.023
Below 0.35μ	1.1	1.17	1.0	1.07	0.64	0.63	0.27	0.22
Below 0.40μ	3.9	4.22	3.8	3.97	2.8	2.70	1.62	1.3
0.40—0.76μ	43.7	46.8	43.9	45.8	42.1	40.4	39.1	31.4
Total		107.0		104.5		96.1		80.2
	TUNGSTEN FILAMENT LAMPS(e)						TUNGSTEN ARC(f)	
	500-WATT, 1000 HR.		500-WATT, 100 HR.		.900-WATT MOVIE			
	Per Cent	Milliwatts	Per Cent	Milliwatts	Per Cent	Milliwatts	Per Cent	Milliwatts
0.31—0.29μ	0.011	0.00044	0.015	0.0006	0.030	0.0028	0.095	0.0108
Below 0.325μ	C.032	0.0013	0.042	0.0017	0.083	0.0076	0.26	0.030
Below 0.35μ	0.08	0.003	0.10	0.004	0.18	0.017	0.52	0.059
Below 0.40μ	0.31	0.012	0.38	0.015	0.63	0.058	1.53	0.17
0.40—0.76μ	15.7	0.63	16.7	0.67	19.4	1.8	27.0	3.1
Total		4.0		4.0		9.2		11.4

(a). The rays from the sun are assumed to fall upon a surface perpendicular to the direction of propagation.
(b). For June 21 at latitude of Cleveland (O).
(c). For Feb. 15 at latitude of Cleveland.
(d). For Dec. 21 at latitude of Cleveland.
(e). The energy from the tungsten lamp is the amount falling on a square centimeter at a distance of one meter from the lamp.
(f). Calculated for one square centimeter of molten tungsten.

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(9) *Jour. Amer. Med. Assoc.*, *88*, 1362, May, 1927

(10) *Smithsonian Miscellaneous Collection*, *74*, p. 15, 1923. *Annals Astrophysical Observatory*, *2*, p. 112, 1908.

(11) *Comptes Rendues*, *175*, p. 156, 1922. *Astrophys. Jour.*, *54*, p. 297, 1921.

(12) Sonderdruch aus "Gerlands Beitrage zur Geophysik," *XVI*, p. 344, 1927.

the sun's spectrum outside the earth's atmosphere, the distribution of energy from the sun reaching the earth's surface can be calculated. Having the distribution of energy in the sun's spectrum that reaches the earth's surface, the actual percentages in the different regions were obtained by step-by-step integration. Making use of Abbot's(13) solar constant, it was possible to express these percentages in the various wavelength intervals of the sun's spectrum in watts per square centimeter. The figures given are, of course, for the direct rays of the sun and not for any radiation that may reach a square centimeter of surface due to scattering. These values are for the average distance of the sun from the earth. If the variation of the distance of the sun from the earth is considered, it will give a variation of about ±3 per cent in the energy.

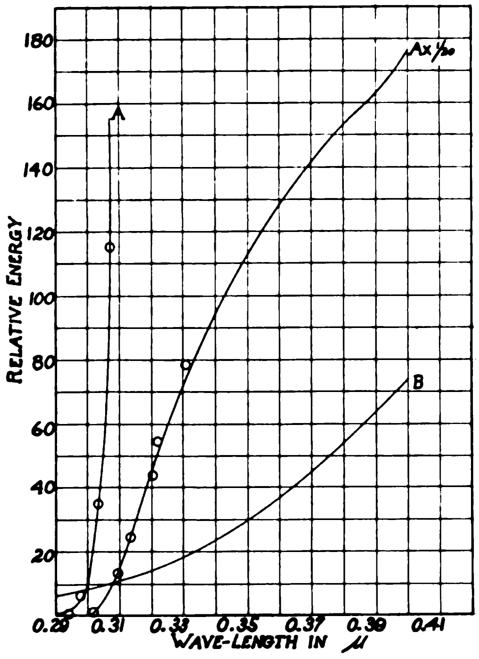

Fig. 4. Energy Distribution in the Ultra-violet Region. Values as plotted show the amount of energy per second falling on a square centimeter of the earth's surface for the sun directly overhead, and the energy per square centimeter per second from the tungsten filament lamp at a distance of one meter from the lamp

Curve *A*—Energy from the sun
Curve *B*—Energy from the 900-watt tungsten movie lamp perpendicular to plane of filament
O—Unpublished values from Brian O'Brien
Curve marked $A \times 1/20$ same as Curve *A* but plotted with the energy multiplied by $1/20$.

A check of the amount of energy in the solar spectrum for the region between 0.29 and 0.325μ was obtained by making use of some results in a paper by Holladay.(14) In this paper there was presented a very convenient method of calculating the percentage of energy in the different spectral regions of a black body. The distribution of energy in the solar spectrum outside the earth's atmosphere corresponds very nearly to that of a black body at 6000 deg. K.(11) According to Holladay's results, there is about 2.7 per cent of the energy of a black body at 6000 deg. K. in the region between 0.29 and 0.325μ. The transmission for the curve given in Fig. 2 for the energy of a black body in this region at this temperature amounts to about 8 per cent. This indicates that there is about 0.22 per cent of the energy of the sun between wavelengths 0.29 and 0.325μ that reaches the earth's surface, which is in very good agreement with the foregoing results.

Coblentz(15) gave some data on the ultra-violet energy of the sun as measured at Washington. These measurements showed that on clear days about 2 per cent of the solar energy that reaches the earth's surface is of wavelengths shorter than 0.39μ. This is also in good agreement with the preceding results obtained by calculation.

Kimball gave the results of some calculations on the distribution of energy in the solar spectrum in a paper presented before the International Illumination Congress at the meeting at Saranac in September, 1928. His conclusions agree well with the values given in this article, where these overlap.

In Fig. 4 is shown the relative amount of energy in the ultra-violet region from the 900-watt movie lamp and the sun. These values are for the amount of energy per second falling on a square centimeter normal to the lamp at a distance of one meter from the lamp, and the amount falling on one square centimeter of horizontal surface from the sun. The values thus obtained are for the sun directly overhead. It is generally admitted that the energy from the sun in such a position is more than people can stand who are not accustomed to this intensity; and even people living in such regions do not stay out in the sun for any great length of time. It is to be noted that the sun is never directly overhead except for a region 23½ deg. north or south of the equator, and even in that region the sun is directly overhead only at noon. It is also quite likely that this amount of ultra-violet energy is very greatly in excess of what is needed for the promotion of health and growth in human beings. It is almost certain that a very short exposure to such radiation will result in very violent sunburn. Different people have often reported that they are very badly sunburned by exposure of their arms and face while playing tennis in Cleveland after 4:30 p.m. (sun time). In view of this, it was thought of interest to calculate the intensity of the ultra-violet energy from the sun for the two wavelength limits for different times of day and for different seasons of the year. The length of the path of the sun's rays through the atmosphere varies as the secant of the angle of the sun's elevation. Making use of this relation, the transmission of the earth's atmosphere for different wavelengths was calculated for the following air masses: 1.0, 1.07, 1.5, 2.0, 2.37, and 3.0. From the transmissions for an air mass of unity and the spectral intensity of the sun's energy outside the atmosphere, the intensity of the sun's energy reaching the earth's surface was calculated for the different air masses named, and the amount in the different wavelength intervals calculated. These values were, of course, corrected for the fact that the sun's rays do not fall perpendicularly upon a horizontal surface.

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(13) *Annals Astrophysical Observatory*, *4*, p. 192, 1922.
(14) *J.O.S.A.*, *17*, p. 329, 1928.
(15) *Bulletin of the Bureau of Standards*, *16*, p. 240, 1920.

By plotting a curve showing the relation between air mass and intensity of solar radiation for different wavelength regions, the amount of energy for the wavelength regions reaching the earth's surface at different times of day and at different seasons of the year can be obtained. From such data the curves in Figs. 5 and 6 were obtained. The curves in Fig. 5 show the intensity of the energy in the sun's spectrum below 0.325μ for four periods of the year: winter and summer solstices, and spring and fall equinoxes. Fig. 6 shows like data for the amount of energy below 0.31μ. In Fig. 7 is shown the variation of the ultra-violet energy in the wave-length limit 0.31 to 0.29μ at noon for the different periods of the year for the latitude of Cleveland.

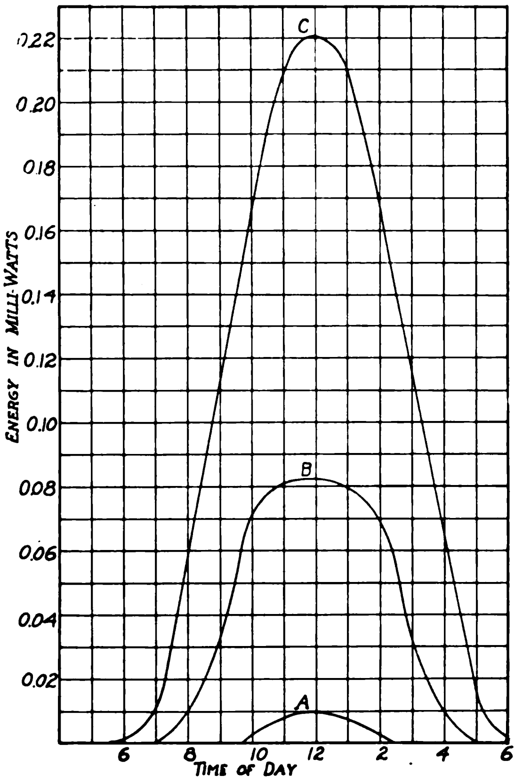

Fig. 5. Ultra-violet Energy Below 0.325μ from the Sun Falling on a Square Centimeter of the Earth's Surface Per Second for Latitude of Cleveland (O.) for Different Times of the Day and Different Seasons

Curve *A* —Winter solstice
Curve *B* —Spring and fall equinoxes
Curve *C* —Summer solstice

Prof. Winchester[16] has been studying the ultra-violet wave-length limits of the sun's energy at New Brunswick (N. J.) for a number of years. In Fig. 8 is shown his curve for these limits for different periods of the year. The values for the equinoxes for his wave-length limits were taken from the foregoing calculation of the energy reaching the earth's surface, assuming that this was the minimum amount of energy necessary to affect the photographic plate. The wavelengths for this same energy for four other values were plotted on his curve. As is shown in the curve, the agreement is good.

As a basis of comparison, shall the maximum of the ultra-violet energy possible from the sun be taken or shall the minimum be used? In sanatoriums in general, sunbaths are not given in the middle of the day in the summer months. In the work referred to on glass substitutes,[9] it was shown that the winter's sun at Boston was of sufficient energy in the ultra-violet region to prevent rickets in chickens. The time average of the intensity of the ultra-violet energy for the four days represented in the curves in Fig. 5 and 6 gives a value of 0.048 watts per square centimeter for the wavelength limit 0.325 to 0.29μ and 0.0034 for the short wavelength limit. This is more than the intensity of the ultra-violet energy from the sun at Cleveland at 4:30 p.m., in June, and also more than the maximum intensity of the ultra-violet energy at Boston during January and February. There does not seem to be much doubt that but a very few hours exposure per day to ultra-violet energy of this intensity would be sufficient for many therapeutic purposes. From these considerations, the time average of the sun's intensity in the ultra-violet region will probably make a very good standard.

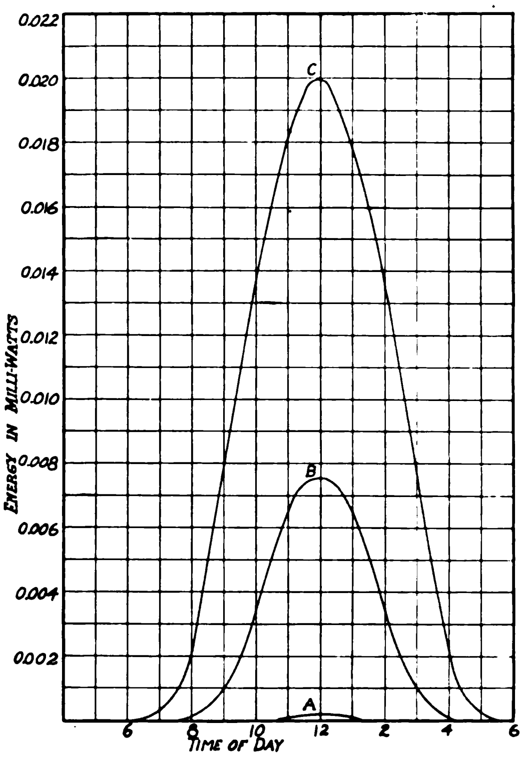

Fig. 6. Ultra-violet Energy Below 0.31μ from the Sun Falling on a Square Centimeter of the Earth's Surface Per Second for Latitude of Cleveland for Different Times of the Day and Different Seasons

Curve *A*—Winter solstice
Curve *B*—Spring and fall equinoxes
Curve *C*—Summer solstice

The figures in Table I show that the amount of the sun's energy in the so-called "vital ray" region that reaches the earth is not very much greater than from the 900-watt movie lamp at a distance of one meter.

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(16) Unpublished data furnished by Prof. George Winchester. See also Riddle, *J.O.S.A. 18*, p. 442, June, 1929.

even for the best conditions possible for the sun. If there is any very great amount of dust or smoke, the "vital" ultra-violet radiation from the sun is very greatly reduced, if not wholly absorbed.[8] It is very doubtful if any of the ultra-violet energy in this "vital" region is received from the sun in winter at or near a great city where the dust and smoke are quite thick.

Column 4 of Table II shows a comparison of the ultra-violet energy in the region 0.325 to 0.29μ from the sun and some tungsten filaments,[17] and also for comparison in Columns 2 and 3 the illumination and total energy received per square centimeter from each source. The ultra-violet for the region 0.31 to 0.29μ is shown in Column 5. The figures for tungsten filaments have been calculated without allowing for the transmission of the bulb. For a glass bulb, of course, the very short wavelength ultra-violet energy is wholly absorbed and thus eliminated. If a quartz bulb is used, about 90 per cent must be allowed for the factor, *i.e.*, the figures given would have to be reduced by about 10 per cent. The transmission of the quartz substitute glasses varies from about 30 to 80 per cent for this region.

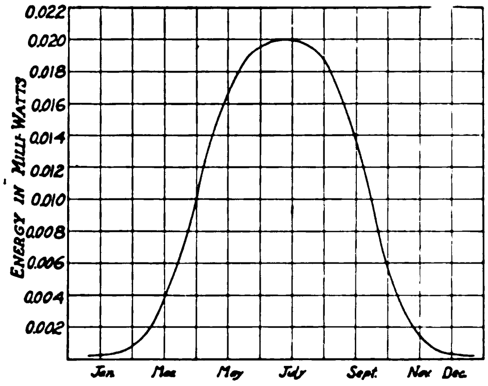

Fig. 7. Ultra-violet Energy Below 0.31μ from the Sun Falling on a Square Centimeter of the Earth's Surface Per Second for the Latitude of Cleveland for Different Times of the Year for 12 o'clock Noon

The vertical line above each month denotes its beginning.

TABLE II

TOTAL ENERGY, ILLUMINATION, AND ULTRA-VIOLET ENERGY FROM THE SUN AND SOME TUNGSTEN FILAMENT LAMPS

Source	Illumination (Foot-candles)	Total Energy (Milliwatts per cm.²)	ULTRA-VIOLET ENERGY FALLING ON A CM.² OF SURFACE (MILLIWATTS)	
			Below 0.325μ	Between 0.31&0.29μ
Sun(a) 1 atm.	8540	107	0.26	0.024
1.07 atm.(b)	7900	97.6	0.21	0.019
1.5 atm.(c)	4940	64.0	0.07	0.0041
2.37 atm.(d)	2415	33.9	0.010	0.00017
500-watt tungsten(e) lamp, 1000 hr. life	71	4.00	0.0013	0.00044
500-watt tungsten lamp, 100 hr. life	87	4.00	0.0017	0.00060
900-watt movie(e)	292	9.2	0.0076	0.0028
Tungsten arc(f)	544	11.4	0.030	0.0108

(a). The energy and illumination from the sun are corrected for the sun's distance from the zenith, *i.e.*, are for a horizontal surface.

(b). June 21 for latitude of Cleveland (O.).

(c). About February 15 for latitude of Cleveland (O.).

(d). December 21 for latitude of Cleveland (O.).

(e). The values for the tungsten filament lamps and arc for a cm.² at a distance of one meter from the lamp.

(f). Calculated for one cm.² of molten tungsten.

From the figures given in Table I it can be seen that it is possible to obtain per square centimeter an amount of energy from the tungsten filaments that is of the same order as that obtained from the sun. If the comparison is made on the basis of equal energy or equal illumination, it is much more favorable for the tungsten filaments. For the same energy per square centimeter, there is about three times as much ultra-violet energy between 0.325 and 0.29μ from the 900-watt movie lamp as from the sun in winter; while for the sun directly overhead the movie lamp will show about one-half as much ultra-violet energy in this region as the sun. The data in Table II are much more favorable for the tungsten filaments. As is shown, for about one-tenth the energy per square centimeter the tungsten filament gives about one-tenth as much energy in the ultra-violet region, 0.29 to 0.31 μ, as the sun at the maximum. The ultra-violet energy between 0.29 and 0.31 μ from the 500-watt tungsten filament lamp operated at 100 hours' life compares very favorably with that from the sun on the basis of equal total energy. By the use of reflectors with the tungsten lamps, the amount of energy in the different wavelength regions falling on a square centimeter as considered could be very greatly increased.

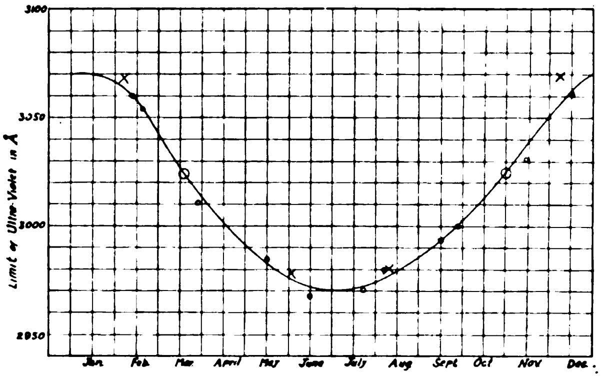

Fig. 8. Prof. Winchester's Limit of Blackening on Photographic Plates for North Sky at New Brunswick (N. J.) for Different Seasons of the Year

The vertical line above each month denotes its beginning.
o—Winchester s values
O—Two points from calculations in this article made to fit the curve
X—Other points plotted from data in this article.

It must be remembered also that it is in the winter months that the need is greatest for the ultra-violet energy. If children in their play-rooms or schoolrooms were under illumination from the tungsten filaments in ultra-violet transmitting bulbs, the foregoing figures and data indicate that they might be supplied with a considerable amount of the desirable ultra-violet energy, without being subjected to too great an amount of energy or too high a level of illumination. It must be remembered also that a much greater portion of the body could be exposed in a warm room than is possible out of doors on a winter day. When all these factors are considered, it is evident that more work should be done on both the physical measurement of the ultra-violet energy from a tungsten filament and upon its therapeutic value.

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(17) Compare Stockbarger, et al., *J.O.S.A.*, *18*, p. 53, Jan. 1929.

Cathode-ray Oscillograph Study of the Operation of Choke Coils on Transmission Lines

Consideration of Standard Choke Coils and Coils of Much Larger Inductance—With and Without Arrester—Test Results Show Choke Coils in General Are Not Worth While

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General Electric Company

CHOKE coils of comparatively small inductance (0.034 millihenrys) have been used for many years in combination with lightning arresters for the protection of station apparatus. The choke coil was intended not only to assist the operation of the arrester, by reflecting the incoming wave so that the arrester operates more quickly than it otherwise would have done, but also to prevent the application of the impulse to the transformer winding until after the arrester had reduced the impulse to a low value at the line terminal of the choke coil.

In the last few years a large amount of information has been collected with respect to surges on transmission lines due to lightning.(1) These studies show that perpendicular waves rarely if ever occur and indicate that the majority of impulses due to lightning will not reach their crest voltages in a time less than one microsecond. Information is now available showing the possible duration and rate of decay of such lightning transients. Having this information, it is now possible to apply "man-made lightning" to transmission lines with considerable assurance that the effects will in general be the same as could be caused by natural lightning.

Since the cathode-ray oscillograph has been available, much information has been gained from laboratory tests; but it has been felt, particularly in the case of lightning arresters, that until high-voltage surges were placed on full-size transmission lines and their effects studied with the cathode-ray oscillograph, the data could not be used with complete assurance. During the summer of 1928 such a study was begun on the Turners Falls 66-kv. transmission line, using a portable impulse generator giving an open-circuit potential of 400,000 volts. The work of the summer of 1929 has included a study of the operation of the choke coil when connected to a transmission line with arrester and transformer connected as in service. Only a brief description of the impulse generator and oscillograph equipment will be given here, as descriptions have already been published.(2)

Apparatus

All of the tests were made at the Silver Lake Station of the Pittsfield Electric Company, where a two-circuit transmission line belonging to the Turners Falls Power and Electric Company terminates. This line is insulated with six Hewlett insulators, and has one ground wire at the top of the steel towers. The impulse generator was located at Tower 279, which is 5.77 miles from the Silver Lake Station. Previous tests and calculations indicate that the surge impedance of the transmission line may be taken as approximately 500 ohms.

The impulse generator has an electrostatic capacity of 0.0156 microfarads. Tests were made with two wave-fronts, one reaching crest voltage in about two microseconds and the other in about eight microseconds. In every case the impulse generator was initiated by a small impulse applied to the lower conductor and so timed that the cathode-ray oscillograph was energized in time to record, at the Silver Lake Station, the front of the incoming wave. The impulse generator was connected to the middle conductor, to which was also connected the apparatus undergoing test at Silver Lake, 5.77 miles away.

The cathode-ray oscillograph is of the cold-cathode type and is located at the Silver Lake Station. The circuit arrangement for this apparatus has already been published.(2) In making the choke-coil tests here described, it was necessary to measure voltages at some distance from the oscillograph. For this purpose, use was made of Gabor's method,(3) which permits a reduction in potential of the wave to be measured so the oscillograph deflection may be kept within proper limits. A cable approximately 140 ft. in length was connected to the transmission line, at the point where measurements were desired, through a capacitance in series with a high resistance. The surge impedance of the special cable used was 280 ohms. At the oscillograph end of the cable a resistance equal to the surge impedance of the cable was connected in series to ground, together with a capacitance of 0.5 to 0.25 microfarads, depending on the reduction ratio desired. The oscillograph was then connected between the conductor of the cable and ground, thus placing the deflecting plates in parallel with the resistor and the capacitor. This method was checked against other means of reducing and conducting the transients for registration, so that the results may be considered as being reasonably accurate. Two inductance coils were studied, one designated L_1, having an inductance of 3.88 millihenrys, and the other L_2, having an inductance of 0.034 millihenrys. The latter coil, L_2, is shown in Fig. 1 and is a standard choke coil rated 100 amp.

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(1) Symposium on Lightning Investigation, A.I.E.E. Mid-winter Convention, February, 1930.

(2) "Cathode-ray Oscillograph Study of Lightning Surges on the Turners Falls Transmission Line," by K. B. McEachron and V. E. Goodwin, *Trans. A.I.E.E.*, July, 1929, Vol. 48.

(3) "Oszillographieren von Wanderwellen mit dem Kathodenoszillographen," by D. Gabor, *Forschungshefte der Studiengesellschaft fur Hochstspannungsanlagen*, Sept., 1927, Vol. 1.

The transformer used in combination with the choke coils is rated 8000 kv-a., 3 phase, 66,000/114,000Y-2300, connection being made to the 66,000-volt winding. The length of circuit between the choke coil and transformer, when tested together, was about 30 ft.

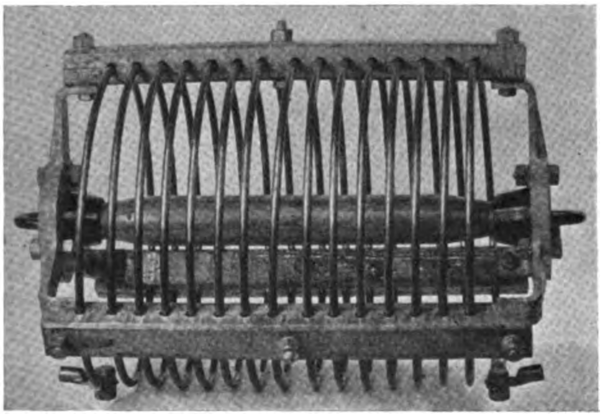

Fig. 1. Standard 100-amp. Choke Coil. Suspension type

Two lightning arresters of identical rating were used in the test, one an oxide-film arrester and the other a special arrester. In no case did the arrester connections exceed 10 ft. in length, the arrester always being connected on the line side of the choke coil and between line and ground. The station ground bus was used for grounding in all cases.

The object of the investigation was threefold:

(1). To determine whether the operation of the modern valve-type lightning arrester is improved by the use of a choke coil.

(2). To find out whether the present choke coil is harmful.

(3). To determine what can be done to improve any beneficial action of the choke coil, or to mitigate its harmful action if such is found to exist.

It has been felt for some time that choke coils could be beneficial only on the steepest waves, and therefore if it could be shown that an inductance one hundred times as great as that of the usual choke coil was of little benefit even with steep waves, then it would be certain that a standard small coil would be of even less benefit. Therefore tests were first made with the large coil previously mentioned. If, on the other hand, it was found that the large coil was beneficial to the operation of the arrester, then means such as shunting the coil with resistance should be employed to reduce the harmful effect which such a coil would introduce when used in combination with a transformer. It has long been known, of course, that inductance in series with capacitance could give rise to oscillations which might attain crest values of potential twice as great as the original disturbing potential, and it is this oscillation which may assume sufficient magnitude to be of importance.

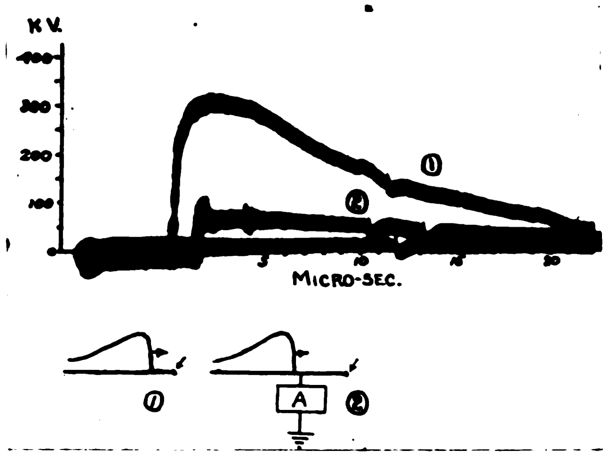

Fig. 2. (*1*) Open-circuit Voltage. Fast wave
(*2*) With Special Arrester Connected at End of Line

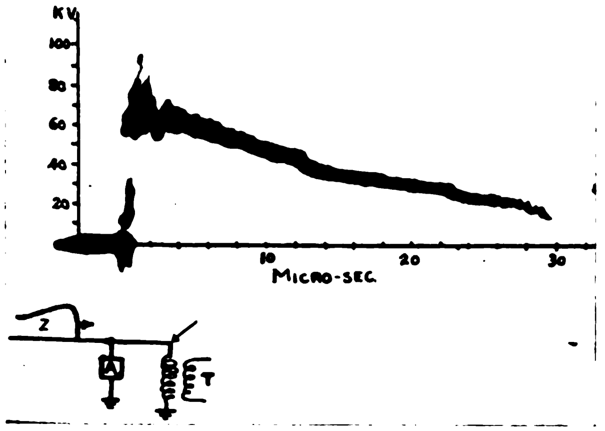

Fig. 3. Fast Wave Applied to Special Arrester and Transformer

Results

In making an investigation of this character it is desirable that the actions of the various parts of the circuit be well enough understood so that calculations may be based on assumptions which are known to be reasonable. The transformer has frequently been considered as a capacitance for the first 50 to 100 microseconds.[4] To check the validity of such an assumption, the open-circuit wave shown in Fig. 2 was applied to the special arrester connected to protect the transformer, as in the circuit diagram in Fig. 3.

The same wave was then applied to the same arrester connected in parallel with a capacity of

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[4] "Lightning Studies of Transformers by the Cathode-ray Oscillograph," by F. F. Brand and K. K. Palueff, *A.I.E.E. Journal*, July, 1929, Vol. 48, pp. 542.

0.001 microfarads, as shown in Fig. 4. Comparing Figs. 3 and 4, the substitution of the capacity for the transformer is seen not to alter the arrester characteristic.

In Figs. 5 and 6 oscillograms are shown of the potential across the transformer and capacitor respectively, when connected in series with the large inductance (3.88 millihenrys). The special arrester is connected in each case as shown in the circuit diagram.

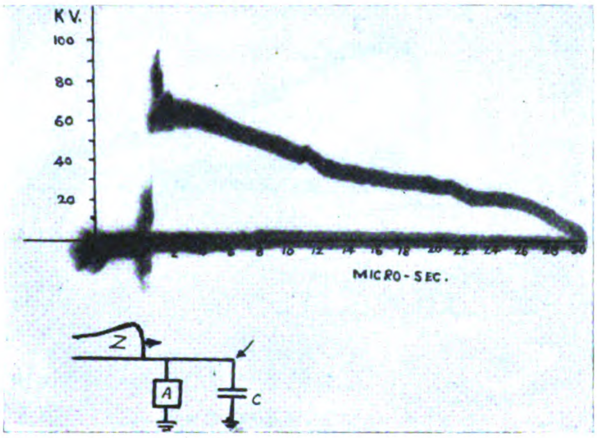

Fig. 4. Fast Wave Applied to Special Arrester and Capacitor of 0.001 m.f.

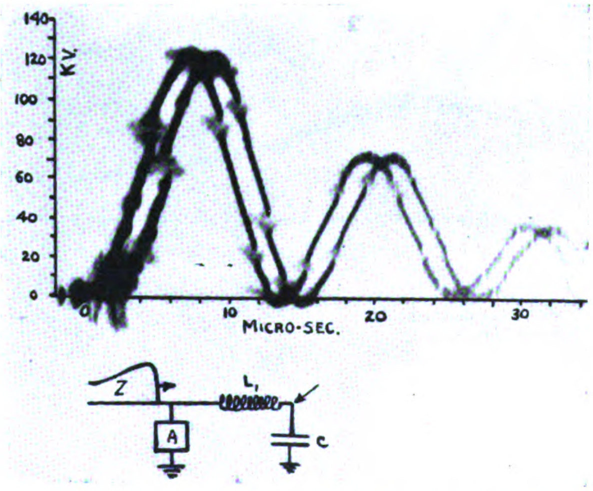

Fig. 6. Capacitor Voltage with Fast Wave Applied to Special Arrester and to Capacitor of 0.001 m.f. in Series with 3.88-millihenry Coil. Two exposures

The oscillograms of Figs. 5 and 6 each show a similar oscillation which can be shown to be about the arrester characteristics of Fig. 3 and 4 as an axis. The frequency of the oscillation with the transformer is such that the transformer may be considered as acting like a capacity of 0.00139 microfarads. Thus for a time of at least 30 microseconds, the transformer acts like a capacitance; and in many of the tests which follow, the transformer will be represented by a capacitor. It is fortunate that the transformer acts in this manner for a brief interval, as it tends to simplify the calculations greatly.

The question has often been raised as to how much the capacity of the transformer with its bushing will alter the incoming wave, the presence of the choke coil or other series inductance not being considered. Oscillograms not reproduced here show that the open-circuit wave at the end of the transmission line and the wave appearing at the transformer terminal differ only in that the wave with the transformer is not quite so steep as the open-circuit wave. This agrees with the conclusion reached by Brand and Palueff.(4) Calculation does show a small difference in the wave due to the presence of the capacity of the transformer, but for all practical purposes it may be said that the wave upon reaching the transformer will reflect to practically double the potential of the incoming wave.

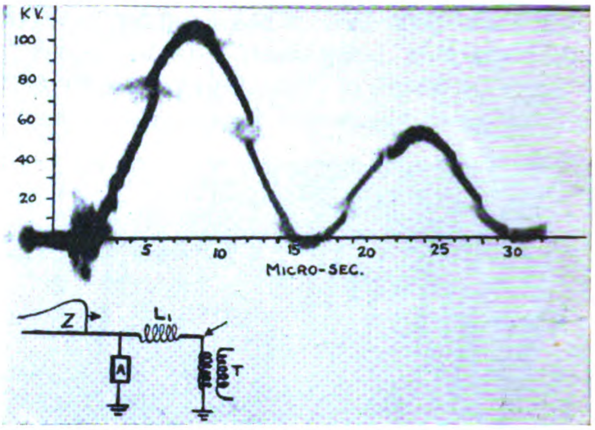

Fig. 5. Transformer Voltage with Fast Wave Applied to Special Arrester and to Transformer Through 3.88-millihenry Coil

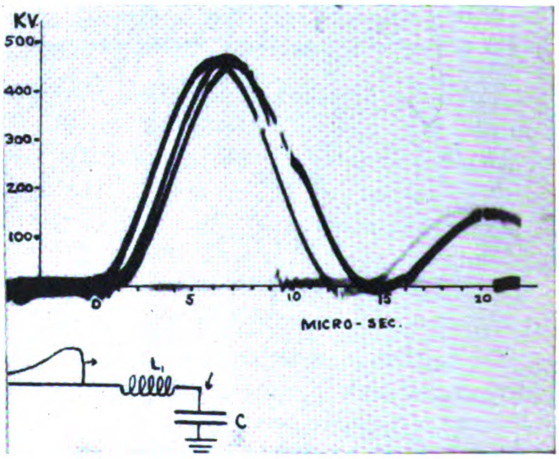

Fig. 7. Capacitor Voltage with Fast Wave Applied to 0.00114-microfarad Capacitor Through 3.88-millihenry Coil. Three exposures

It was shown in Figs. 3 to 6 that the potential on the transformer side of the coil oscillated about the arrester voltage as an axis. Fig. 7 shows the oscillation inside the large inductance coil with no arrester connected, and comparing this with Fig. 2 it will be seen that the oscillation is about the applied wave as an axis. The potential measured inside the coil is nearly double that of the open-circuit wave, which in turn is practically double the traveling wave out on the transmission line.

Based on the foregoing tests certain conclusions regarding these oscillations may be formed. If the current taken by the arrester is large compared to that taken by the inductance, then the voltage across the arrester terminals may be taken as the wave applied to the inductance. Thus, in general, when an arrester is used the oscillation depends on the arrester volt-time characteristic the form of which is largely determined by the form of the incoming wave. The amplitude will depend not only on the magnitude of the applied wave, but on the rate of damping, which is dependent on the resistance of the arrester at the particular instant considered. The maximum value of the first crest of the oscillation depends both on the rate of damping and on the frequency of the oscillation, which depends on the value of the inductance of the coil and the capacitance of the transformer. In general, the higher the frequency of oscillation the higher will be the first crest, also the slower the damping the higher will be the first crest of the oscillation.

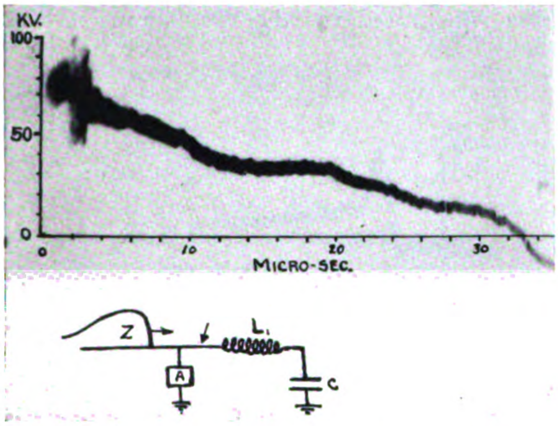

Fig. 8. Arrester Voltage with Fast Wave Applied to Special Arrester and to 0.001-microfarad Capacitor Through 3.88-millihenry Coil

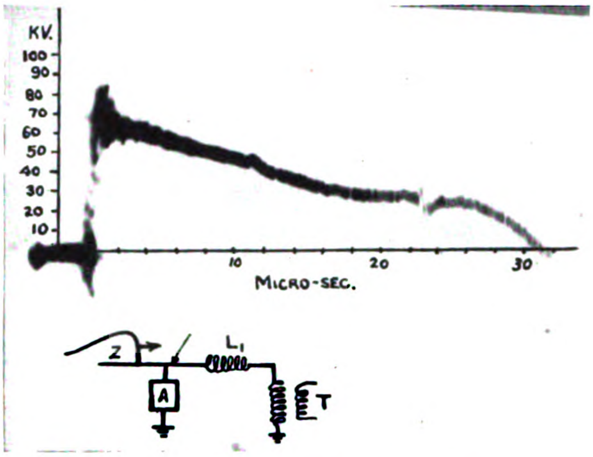

Fig. 9. Arrester Voltage with Fast Wave Applied to Special Arrester and to Transformer Through 3.88-millihenry Coil

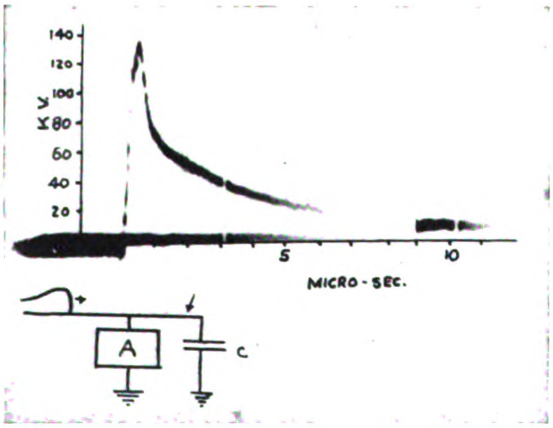

Fig. 10. Capacitor and Arrester Voltage with Fast Wave Applied to Oxide-film Arrester and to 0.00114-microfarad Capacitor

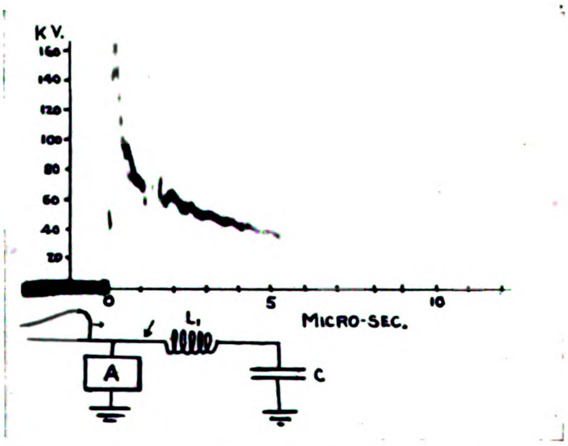

Fig. 11. Arrester Voltage with Fast Wave Applied to Oxide-film Arrester and to 0.00114-microfarad Capacitor Through 3.88-millihenry Coil

Comparing Fig. 4 with Fig. 8 and Fig. 3 with Fig. 9, it is clear that the operation of the arrester is not materially altered by the presence of an inductance of 3.88 millihenrys, which is about one hundred times that of the usual choke coil. Similar oscillograms for the oxide-film arrester are shown in Figs. 10 and 11, except in this case the potential across the arrester is higher with the coil, both on the front and on the tail of the wave.

Based on these data, it seems clear that at least for the two types of arresters investigated the operation of the arrester is not improved by the use of a choke coil of much larger inductance than now is used. It may be concluded therefore that the use of the choke coil is not beneficial to the operation of the modern lightning arrester.

Tests with Choke Coils

When the standard choke coil (inductance equal to 0.034 millihenrys) is used, no oscillation takes place due to the incoming wave alone. This condition is illustrated in Figs. 12 and 13, which show first the potential on the line side of the coil and second the potential on the transformer side of the coil, the transformer being replaced by the capacitor. These oscillograms which show no oscillation are to be compared with the oscillogram shown in Fig. 7, the only difference between Figs. 13 and 7 being in the amount of series inductance. In the case of the standard choke coil, the inductance is so small that the surge impedance acts to make the condition non-oscillatory.

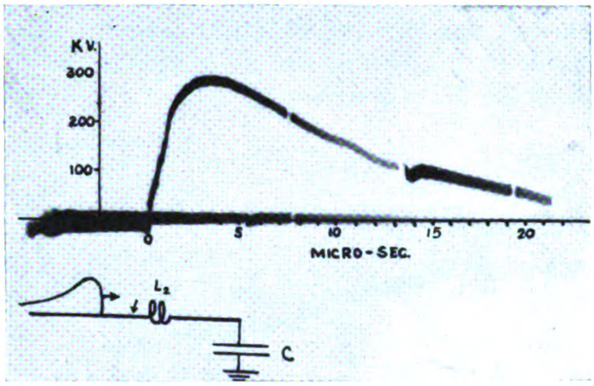

Fig. 12. Voltage Outside Coil with Fast Wave Applied to 0.00114-microfarad Capacitor Through 0.034-millihenry Choke Coil

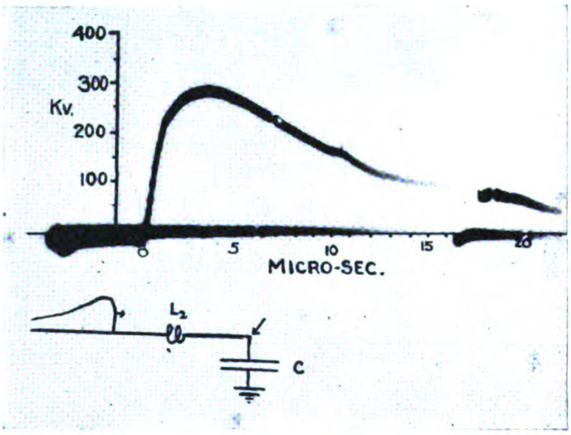

Fig. 13. Capacitor Voltage with Fast Wave Applied to 0.00114-microfarad Capacitor Through 0.034-millihenry Choke Coil

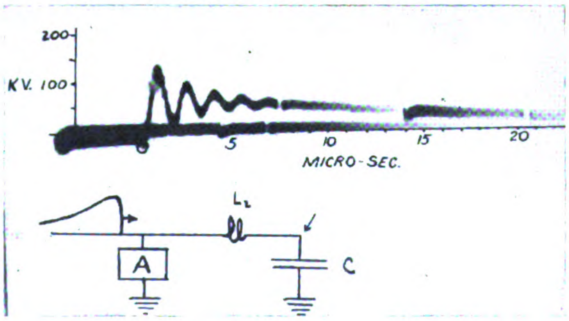

Fig. 14. Capacitor Voltage with Fast Wave Applied to Special Arrester and to 0.00114-microfarad Capacitor Through 0.034-millihenry Choke Coil

If a lightning arrester has a characteristic such that the IR drop and breakdown voltages are not much different in magnitude, the voltage across the capacity representing the transformer will be as in Figs. 14 and 15. Fig. 16 or Fig. 4 show the potential of the special arrester when the capacity is in the circuit alone, while Fig. 14 shows the potential across the terminals of the capacity with the same wave and arrester, but with the standard choke coil in series. These films show that the potential across the capacity has increased considerably owing to the use of the choke coil.

A similar increase appears with the oxide-film arrester, illustrated by the oscillogram in Fig. 15 which is to be compared with Fig. 8, taken under similar conditions. The rate of damping with the oxide-film arrester is higher than with the special arrester, which is due of course to its different arrester characteristic.

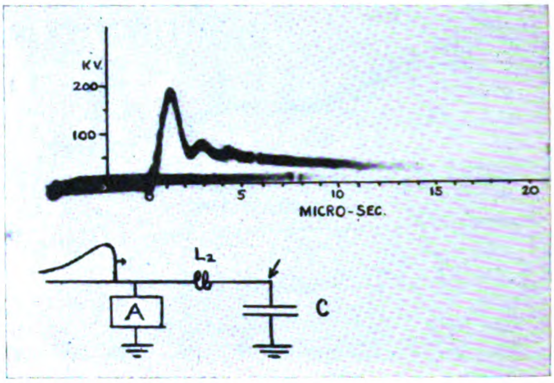

Fig. 15. Capacitor Voltage with Fast Wave Applied to Oxide-film Arrester and to 0.00114-microfarad Capacitor Through 0.034-millihenry Choke Coil

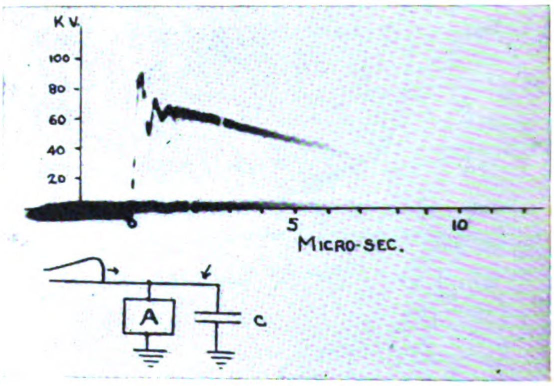

Fig. 16. Arrester and Capacitor Voltage with Fast Wave Applied to Special Arrester and to 0.00114-microfarad Capacitor

Other test records, not reproduced here, made with the slower wave, show that the operation of the arrester and choke coil is not materially different from that with the fast wave shown in the various illustrations. The slow wave does not cause oscillations between the standard choke coil and the transformer, unless a lightning arrester is used in combination with a choke coil.

These results indicate that the same effects will occur whether the wave front is fast or slow, although the arrester characteristics and oscillations, if present, will vary with the shape of the traveling wave.

Conclusions

(1). The use of inductance between a lightning arrester and transformer, even though the inductance is of large value, does not help the operation of the arrester to an appreciable degree.

The following conclusions refer to standard choke coils:

(2). Without an arrester connected, a choke coil having an inductance of the order now used in practice will not oscillate with a transformer having a capacitance of the order of that used in the tests described.

(3). When a choke coil of the magnitude used in these tests is connected between the lightning arrester and the transformer winding, oscillations are likely to occur and their crest potential may exceed that across the arrester terminals.

(4). *The use of choke coils in combination with a transformer and arrester should be discontinued, in order that an arrester such as the oxide-film arrester may give its best protection.*

(5). With high-voltage arresters the resistance to ground will be several times that of the arresters used in this test, which will tend to reduce the possibility of oscillation.

(6). Choke coils may be of slight benefit with arresters whose breakdown voltage is several times the IR drop. This benefit would be present only with very steep waves.

(7). *Choke coils of the usual inductance when used in combination with a transformer, without an arrester, do not protect the transformer, nor are they harmful.*

The author is indebted to Messrs. E. W. Boehne[*] and E. J. Wade, who made the tests, and to Messrs. H. G. Brinton, T. Brownlee, A. Olsen, and others of the staff who assisted in the tests and calculations.

Special thanks are due the officials of the Turners Falls Power and Electric Company and the Pittsfield Electric Company for their coöperation in supplying both men and facilities for the conduct of these tests.

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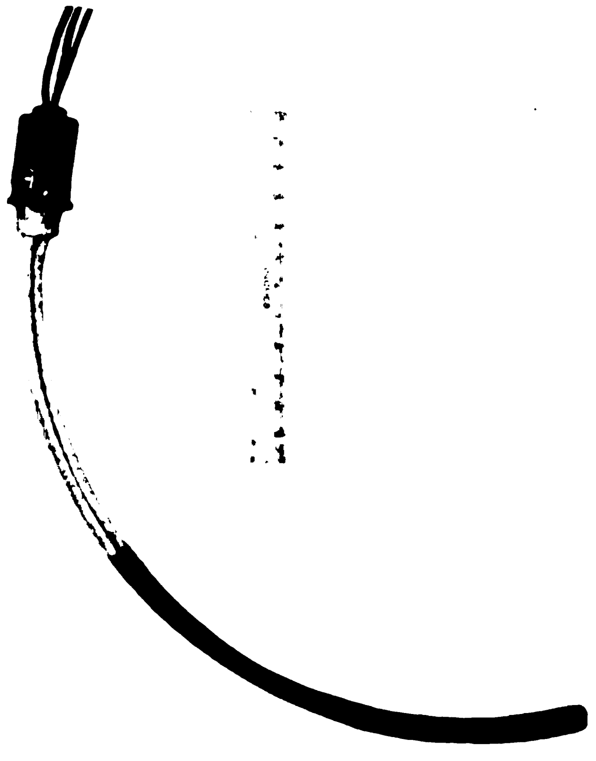
[*] "Calculation of Voltage Stresses Due to Traveling Waves with Special Reference to Choke Coils," by E. W. Boehne, on page 676 of this issue.—EDITOR

New Heater Warms Airplane Engine Oil for Quick Starting



A new electric heating unit, designed for warming the engine oil of aircraft to facilitate quick starting, especially in cold weather, has been added to the list of electrical equipment for airports. The heating unit will operate from the local electric lighting circuit in the hangar.

Cold weather has always presented problems in the starting of aircraft engines. When 'planes are stored in unheated hangars it has been customary, during cold spells, to drain the lubricating oil from the oil tanks after flying operations in the evening and to preheat the oil in the morning before returning it to the tanks.

The new electric heating unit consists of two 110-volt 375-watt heating units conveniently shaped to fit into conventional aircraft oil tanks by insertion through the filter caps. Three degrees of heat are provided: The units can be operated in series for low heat intensity; they can be used as a single unit for intermediate intensity; and they can be operated in parallel for high intensity. The corresponding wattage values are 187, 375 and 750 respectively, at 110 volts.

The new unit is provided with a convenient type of snap switch to give the necessary control for the three heats. It is also equipped with a 35-foot length of cord for attaching to a hangar socket.

The Electric Gauge

Independent of the Human Sense of Touch—Simple and Rapid to Manipulate—Amplification Factor Ten Thousand Times

By A. V. MERSHON, J. W. MATTHEWS and B. C. WAITE, Jr.
General Engineering Laboratory Manager's Office, Schenectady Works
General Electric Company

THE remarkable development in the machine-tool industry during the past few years and the precision requirements of present-day manufacturing have made great demands on the gauge makers for more accurate gauges and gauging devices. Many types of amplifying gauges have been placed on the market to meet this demand, but so far as the writers are aware all but the one here described are either too slow for quantity inspection purposes, or they require a skilled operator, or the mechanism requires frequent repairs or adjustment.

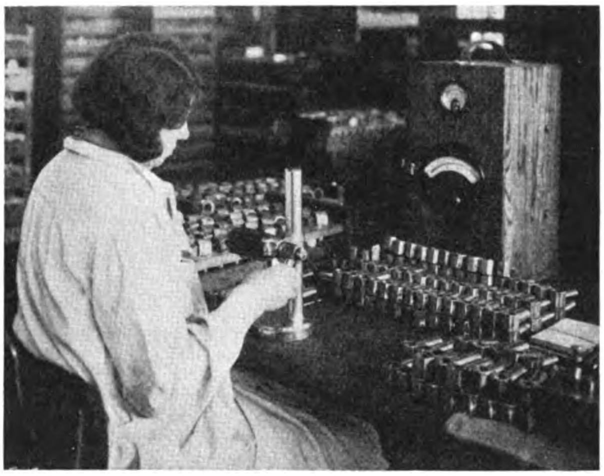


Fig. 1. The Electric Gauge in Operation. The pieces to be tested are placed upon the gaugehead in the foreground and their measurements are indicated on the large ammeter in the face of the cabinet

The electric gauge has been developed to meet the demands for an accurate gauging device that has but a minimum of moving parts and that will permit routine gauging operations to be conducted with great rapidity.

This type of gauge was originally designed for measuring the bore of a hole but by slight changes of the gauging head it can be used for external measurements. During a period of three months 59,000 such holes were tested, yet very little wear could be detected and the electric gauge held its calibration.

Fig. 1 shows the electric gauge set up for making this accurate measurement of production parts. The ammeter, which is the lower instrument in the illustration, deflects full scale for a variation in diameter of 0.0005 in. One ten-thousandth of an inch (0.0001 in.) will give the ammeter needle a scale deflection of one inch. The piece in the operator's hand is rotated once for diameter inspection and the ammeter needle meanwhile observed.

The electric gauge operates entirely independent of the sense of human touch which is so essential in the use of "go" and "no go" plug gauges. A skilled inspector is not required to manipulate the electric gauge as its operation is extremely simple, and quantity production inspection can be carried on at high speed, with only a small fraction of the fatigue that is caused by the use of the plug gauge for internal inspection.

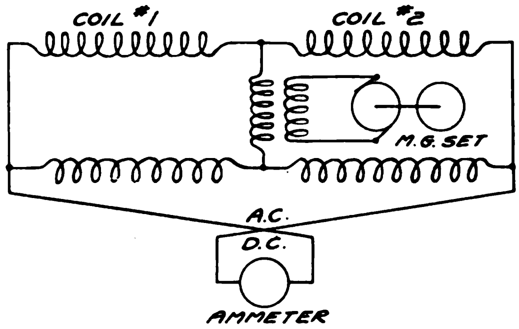


Fig. 2. Connection Diagram of the Electric Gauge

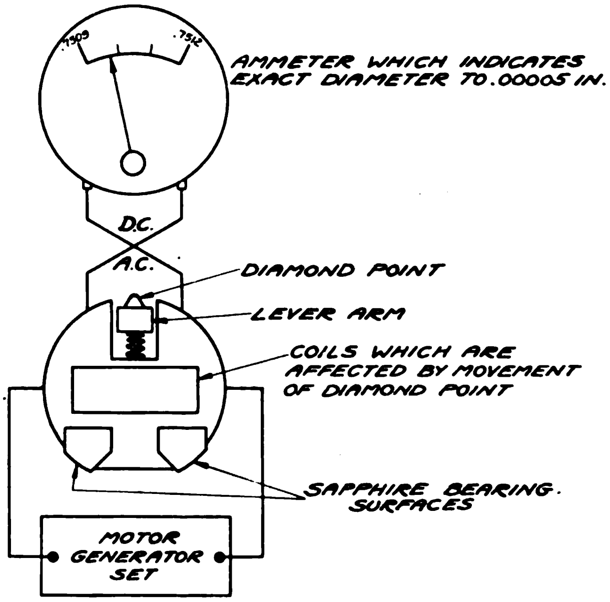

.7509
.7512
AMMETER WHICH INDICATES EXACT DIAMETER TO .00005 IN.
D.C.
A.C.
DIAMOND POINT
LEVER ARM
COILS WHICH ARE AFFECTED BY MOVEMENT OF DIAMOND POINT
SAPPHIRE BEARING SURFACES
MOTOR GENERATOR SET

Fig. 3. Schematic Representation of the Electric Gauge

The electrical operation of the gauge ⁽¹⁾ functions on changing the reluctance of a balanced, differential,

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⁽¹⁾ A more detailed description of this circuit is given in the GENERAL ELECTRIC REVIEW, Nov., 1926, p. 815.

alternating-current circuit (Fig. 2), which in turn operates a direct-current ammeter through a small rectifier.

A smooth, rounded, diamond point mounted on a single lever arm changes the reluctance of the coils in the electrical circuit in proportion to the differences in diameter of the piece of material being gauged. Compression springs (Fig. 3) hold the diamond point in contact with the surface under inspection. A diamond point is used as it is the hardest substance known, and thousands of pieces can be inspected without the point showing any wear. Two sapphire bearing surfaces are used in connection with the diamond point when inside diameter measurements are required, making a three-point contact on the measured surface. The diamond is rated 10 in hardness and sapphire is rated 9, according to scientific knowledge of these elements.

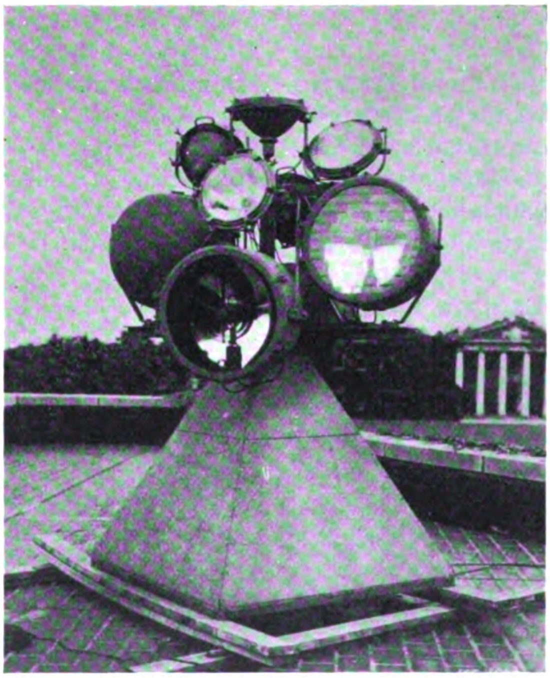
Electric gauge inspection does not cause any mental strain on the operator as the ammeter needle tells the whole story—whether a cylindrical hole is over or under size; out of round, or tapered, or has local irregularities. For calibrating the electric gauge to inspect the cylindrical hole in the pieces shown in Fig. 1, two master gauges were used: one a 0.7509-in. gauge for the minimum dimension and the other a 0.7512-in. for the maximum dimension. These two limits, when marked on the ammeter scale, are three inches apart, and all production pieces must fall within these limits in order to pass inspection. Rotating the piece under inspection will show how much it is out of round. If the piece is perfectly round the ammeter needle will remain stationary when the piece is rotated, but if the piece is out of round by as little as 0.0001 in. the needle will move back and forth one inch on the ammeter scale as the piece is rotated.

According to how rigid an inspection is required, the sensitivity of the electric gauge can be changed by working the lever arm in a larger or smaller air gap; or by changing the location of the diamond point on the lever arm. Flat surfaces and external diameters can also be inspected and measured in a similar manner.

A small 500-cycle motor-generator set, operating on a shop supply circuit, is employed to supply the five watts of energy necessary to operate the electric gauge. Slight fluctuations in the shop voltage do not affect the stability of the electric gauge.

Super-beacon for Airports

A new form of airport beacon, giving a powerful beam of light particularly effective in penetrating banks of fog, has been erected at the Cleveland Municipal Airport.



Incorporated in the design of this multi-light unit are several principles of lighting, each a distinct aid to night pilots. It provides a fan of light which, when rotated, reaches a pilot at any angle at which he may approach the field. One-half of this fan of light is white, and the other half red. The rotation produces alternate red and white flashes, enabling the aviator to distinguish the airport from brightly lighted parks, railroad yards, and streets.

The high-intensity beams are projected by the lower, drum-shaped units, of which there are four—two red and two clear—identical in design with those used to mark airways. The upper units, set to project a less intense beam of light at higher angles, are standard narrow-beam floodlight projectors.

Pilots, airport engineers, and airport operators have commented favorably upon the new beacon from the standpoint of fog penetration, long-range visibility, and as an airport marker. With the increasing number of airports and because of the fact that on clear nights several may be within sight at a given time from a plane, the proper selection of colors for the several units will assist in ready identification of any landing area.

Calculation of Voltage Stresses Due to Traveling Waves, with Special Reference to Choke Coils

Lightning Surges—Apparatus Impedance—Calculation of Voltage Stress with and without Lightning Arrester—Typical Case—Appendix

By E. W. BOEHNE
Advanced Course, Lightning Arrester Engineering Dept., Pittsfield Works
General Electric Company

THIS analysis deals with a determination of voltage stress on station equipment due to traveling surges, and is part of an extensive research program carried on in the interest of the protection of line and station equipment. Particular emphasis is placed upon circuits containing choke coils and reactors used in connection with transformers.

In an article on choke coils,* K. B. McEachron, describes tests which were made and discusses the results of a field investigation, showing with oscillograms taken under operating conditions that the choke coil is not a valuable adjunct to a lightning arrester. Frequent references will be made to oscillograms contained in Mr. McEachron's paper.

The solution of problems in which traveling waves on lines are involved have usually been considered of a complex nature because of (1) the distributed nature of the line constants involved; (2) the variable impedance of the station apparatus to traveling surges; and (3) the irregular form of traveling waves due to lightning. These factors will be taken up briefly in the light of recent investigations.

Traveling Waves Due to Lightning

Actual oscillographic records of natural lightning surges are available. At the close of the season of 1928 only one such oscillogram had been taken; but during the lightning season of 1929 much additional material was obtained,(1) yielding data which show that the experimental wave (Fig. 5) used in the tests is an excellent example of a traveling wave due to lightning. Here we are more interested in wave form than in magnitude, because the magnitude of the voltage stress will be approximately proportional to the magnitude of the traveling wave except in cases when a lightning arrester is used; and even under such conditions the corresponding voltage is readily obtained.

The equation for the wave shown in Fig. 5 is of the form(2)

$$2e = 2E\left\{\epsilon^{-bt} - \epsilon^{-at}\right\} \qquad (1)$$

This wave was measured at the end of an open line, as shown in the diagram, and is therefore twice the value of the traveling wave. In the analysis which follows, this wave form will be used.

Impedance of Terminal Apparatus

Field tests described in Mr. McEachron's article show that a transformer acts as a capacitance(3) for the entire time that the over-voltage caused by the traveling wave assumes dangerous values. This is well demonstrated by comparing Figs. 3 and 4, Figs. 5 and 6, also Figs. 8 and 9 of that article. This eliminates the necessity for any limiting assumptions regarding the impedance of a transformer or transformer bank on the application of traveling waves found in practice.

Determination of Voltage Stress

Here the analysis divides itself into two parts—with and without lightning arresters. Conditions with no arrester will be analyzed first.

Consider(4) the general case (Fig. 1) of a transmission line with junction impedances, B_1, B_2, and B located at the point a. Let the approaching wave (e) enter on the left.

It is desired to determine the reflected wave (e_{r_1}) and the transmitted wave (e_{v_2}) resulting from the applied wave, but it is of greater importance to know the voltage at the terminal of the impedance B, which in the cases under consideration

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*"Cathode-ray Oscillographic Study of the Operation of Choke Coils on Transmission Lines," by K. B. McEachron, on p. 668 of this issue.—EDITOR

(1)Symposium on Lightning Investigations, A.I.E.E. Mid-winter Convention, February, 1930.

(2)"Traveling Waves Due to Lightning," by L. V. Bewley, *A.I.E.E. Journal*, Oct., 1929, p. 729.

(3)The equivalent capacity of a transformer was shown to be $C = \sqrt{C_g\, C_s}$ in a paper, "Abnormal Voltages Within Transformer Windings," by L. F. Blume and A. Boyajian, *Trans. A.I.E.E.*, 1919.

(4)The nomenclature employed in this article is given in the following list:

t = microseconds
e = approaching wave; time equation of approaching wave
e_{v_2} = transmitted wave or wave which passes the point a
e_{r_1} = reflected wave
$Z_1 = \sqrt{\frac{l_1}{c_1}}$ surge impedance of line 1 extending to the left
$Z_2 = \sqrt{\frac{l_2}{c_2}}$ surge impedance of line 2 extending to the right
B_1 = lumped impedance in line 1 at a
$Z_{1(p)} = (Z_1 + B_1)$
B_2 = lumped impedance in line 2 at a
$Z_{2(p)} = (Z_2 + B_2)$
$B = Z_{g(p)}$ = lumped impedance to ground
$Z_{o(p)} = (Z_{1(p)}\, Z_{g(p)}) + (Z_{2(p)}\, Z_{g(p)}) + (Z_{1(p)}\, Z_{2(p)})$
$i_{r1} = -\frac{e_{r1}}{Z_1}$ = reflected current wave
$i_{v2} = \frac{e_{v2}}{Z_2}$ = transmitted current wave
$Z_{(p)}$ = impedance of network from the terminals $m - n$, Fig. 2
$Z_{(p)} = \frac{Z_{2(p)} + Z_{g(p)}}{Z_{o(p)}}$
$A(t)_1 = \frac{1}{Z_{(p)}}\mathbf{1}$
$A(t)_2 = \frac{Z_{g(p)}}{Z_{o(p)}}\mathbf{1}$
E_c = transformer voltage

will be the equivalent capacity of a transformer or transformer bank.

The following procedure is suggested:

(1). Form Fig. 1 into the lumped circuit of Fig. 2, allowing the surge impedances to assume lumped values. Hence Z_1 and Z_2 in Fig. 2 are merely resistances equal to the surge impedance in ohms.

(2). Solve for the current in Z_2 on the application of the voltage e. Hence from Ohm's Law

$$i_2 = \frac{Z_{g(p)}}{Z_{o(p)}} e \qquad (2)$$

(3). Then the following equations exist for the reflected and refracted voltage waves:

$$e_{r_1} = \left\{\frac{Z_{(p)} - 2Z_1}{Z_{(p)}}\right\} e \qquad (3)$$

and

$$e_{r_2} = \left\{\frac{2Z_2 Z_{g(p)}}{Z_{o(p)}}\right\} e \qquad (4)$$

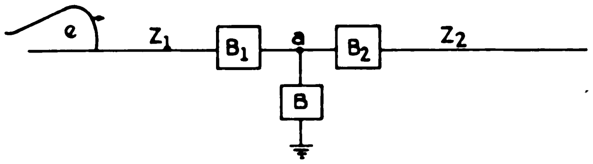

Fig. 1. Schematic Diagram of the General Case of a Transmission Line with Junction Impedances

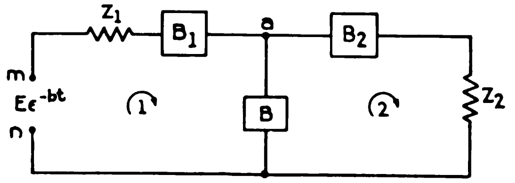

Fig. 2. The Equivalent Diagram of Fig. 1, Showing How the Surge Impedances Become Lumped Resistances in the Closed Circuit

These relations are developed in the appendix from the fundamental wave equations.

When the applied wave is considered rectangular and of unit height, Equations (3) and (4) become

$$e_{r_1} = \{1 - 2Z_1 A(t)_1\} \qquad (6)$$

and

$$e_{r_2} = \{2Z_2 A(t)_2\} \qquad (7)$$

When the applied wave is of the form $e = E\epsilon^{-bt}$, Equations (3) and (4) become(5)

$$e_{r_1} = E\epsilon^{-bt}\left\{\frac{Z_{(p-b)} - 2Z_1}{Z_{(p-b)}}\right\} 1 \qquad (8)$$

and

$$e_{r_2} = E\epsilon^{-bt}\left\{\frac{2Z_2 Z_{g(p-b)}}{Z_{o(p-b)}}\right\} 1 \qquad (9)$$

All of these differential equations are the same as are found in the solution of any simple circuit and their solution may be carried out in any way desired. The foregoing procedure reduces the traveling wave problem to a lumped circuit problem with the time equation of the traveling voltage wave applied to the circuit. It is understood, of course, that when the line terminates in the impedance B, a special case is obtained in which Z_2 is of infinite value.

No attempt will be made to combine the various waves obtained in order to determine the voltage of the station impedance B. A much simpler attack is to return to Fig. 2 and apply $2e$ to the closed circuit, solve for the current through B, and hence the corresponding voltage drop. The reason for this is fundamental and is given in the appendix.

In general

$$E_{ag} = 2\left\{\frac{Z_{2(p)} Z_{g(p)}}{Z_{o(p)}}\right\} e \qquad (10)$$

and when the applied wave is $E\epsilon^{-bt}$ we have

$$E_{ag} = 2E\epsilon^{-bt}\left\{\frac{Z_{2(p-b)} Z_{g(p-b)}}{Z_{o(p-b)}}\right\} 1 \qquad (11)$$

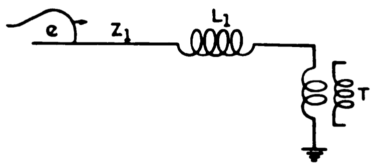

Fig. 3. Particular Case of a Terminal Transformer and Inductance Coil

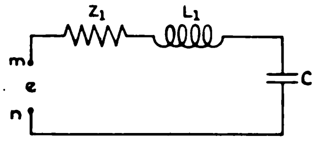

Fig. 4. The Equivalent Diagram of Fig. 3

Equation (10) is general and may be used to determine the voltage at the transformer terminal for any applied wave. Equation (11) is for the particular case of the exponential wave and will be found more useful in as much as the effect of any type of applied wave may be obtained by subtracting a similar solution where the constant b is changed to a, as indicated in Equation (1).

Consider the particular case of Fig. 3. The corresponding closed circuit is shown in Fig. 4. Immediately we see that it would be much simpler to analyze the new circuit and write the answer; however, in applying Equation (11) it is seen that

$$Z_{g(p-b)} = \left\{\frac{1}{C(p-b)}\right\} \qquad (12)$$

and

$$\frac{Z_{o(p-b)}}{Z_{2(p-b)}} = \left\{Z_1 + L\,(p-b) + \frac{1}{C(p-b)}\right\} \qquad (13)$$

Substituting in Equation (11)

$$E_{ag} = \frac{2E\,\epsilon^{-bt}}{LC}\left\{\frac{1}{p^2 + 2ap + \omega_o^2}\right\} 1 \qquad (14)$$

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(5) V. Bush: "Operational Circuit Analysis," John Wiley and Sons, Inc., N. Y., page 133.

where

$$a=\left(\frac{Z_1}{2L}-b\right) \tag{15}$$

$$\omega_o^2=\left\{b^2-\frac{Zb}{L}+\frac{1}{LC}\right\} \tag{16}$$

and when $\omega_o^2>a^2$ the solution becomes

$$E_{ag}=\frac{2E}{LC\omega_o^2}\left\{\epsilon^{-bt}-\frac{\omega_o}{\omega}\epsilon^{-\left(\frac{Z}{2L}\right)t}\sin(\omega t+\phi)\right\} \tag{17}$$

where

$$\omega^2=(\omega_o^2-a^2) \text{ and } \tan\phi=\frac{\omega}{a}$$

then

$$E_c'=513\left\{\epsilon^{-0.104\,t}-1.003\,\epsilon^{-0.0774\,t}\sin(0.422\,t+1.63)\right\} \tag{18}$$

Changing b to 0.77, in accordance with Fig. 6, we have,

$$E_c''=140\left\{\epsilon^{-0.77\,t}-1.927\,\epsilon^{-0.0774\,t}\sin(0.421\,t+2.598)\right\} \tag{19}$$

The transformer voltage becomes

$$E_c=E_c'-E_c'' \tag{20}$$

Equation (20) is the rigorous solution of the transformer voltage when the open-circuit wave shown in Fig. 6 is applied to the circuit. The calculated curve is shown in Fig. 7 and should be compared with the oscillogram taken on the field set-up and shown in Fig. 8. It is evident that the oscillation takes place over twice the applied wave as an axis. The maximum voltages are further controlled by the damping factor $\frac{Z}{2L}$ and the natural frequency of the system, as will be seen by a study of the elements involved.

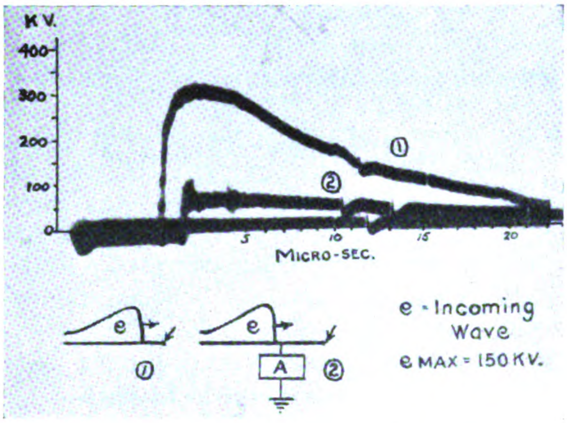

Fig. 5. (*1*) Open-circuit Wave. (See Fig. 6)
(*2*) With Special Arrester Connected at End of Line
(*Compare Fig. 2 of Mr. McEachron's article*)

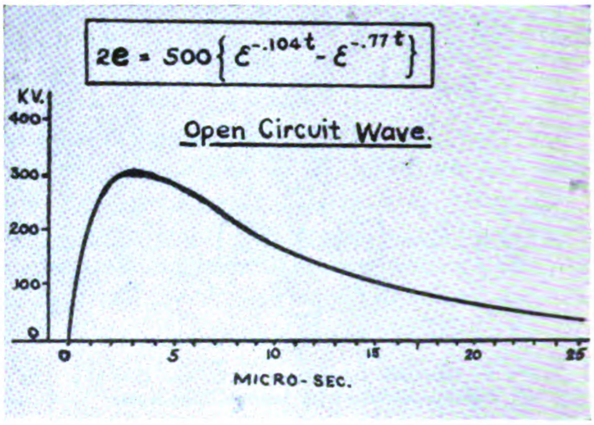

Fig. 6. Equation and Corresponding Curve of the Open-circuit Wave of Fig. 5

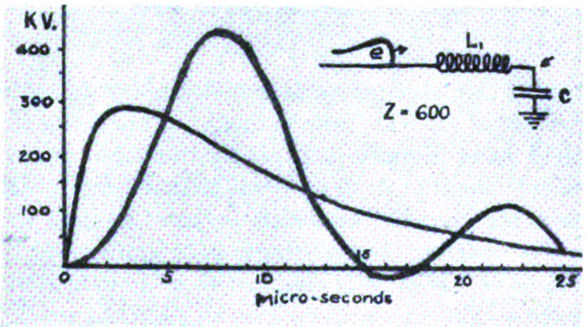

Fig. 7. Calculated Transformer Voltage When the Inductance L_1 of Fig. 3 is 0.00388 Henrys

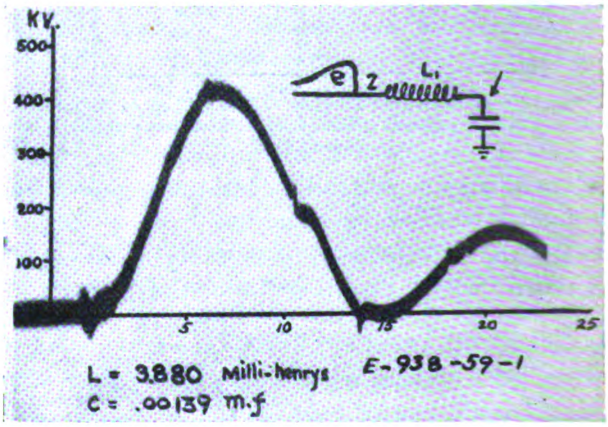

Fig. 8. Oscillogram of Transformer Voltage Under the Conditions of Fig. 3 When L_1 = 0.00388 Henrys. The corresponding calculation is shown in Fig. 7

When $L_1=0.00388$ henrys, which is approximately 100 times the value of the standard choke coil or very close to the inductance of one of the standard reactors,

$C_1=0.00139$ microfarads, which is the capacitance of an 8000-kv-a. transformer;*

$Z_1=600$ ohms, which is the test value of the surge impedance at the point where the apparatus was connected;

$b=0.104$ from the applied wave (see Figs. 5 and 6) and $2E=500$ kv.;

The solution without the reactor for the same wave is

$$E_c'=548\left\{\epsilon^{-0.104\,t}-\epsilon^{-1.19\,t}\right\} \tag{21}$$

and

$$E_c''=1417\left\{\epsilon^{-0.77\,t}-\epsilon^{-1.19\,t}\right\} \tag{22}$$

---

*See the accompanying article by K. B. McEachron.—EDITOR

Superimposing the solutions in accordance with Equation (1)

$$E_c = E_c' - E_c'' \tag{23}$$

Plotting this, the calculated wave shown in Fig. 9 is determined, showing that the transformer voltage is practically equal to twice the applied wave. This is not true for very steep waves, as can be seen by comparing Equation (21) with the applied wave $e = 250\ \epsilon^{-0.104\,t}$. Here, the transformer voltage reaches only 160 per cent of the maximum value of the applied wave in 2.5 microseconds, showing that the time necessary to charge the capacitance of the transformer bank reduces the importance of the steepness of wave front. The general form of Equations (21) and (22) is

$$E_c = \frac{2E}{1 - ZbC}\left\{\epsilon^{-bt} - \epsilon^{-\frac{t}{ZC}}\right\} \tag{24}$$

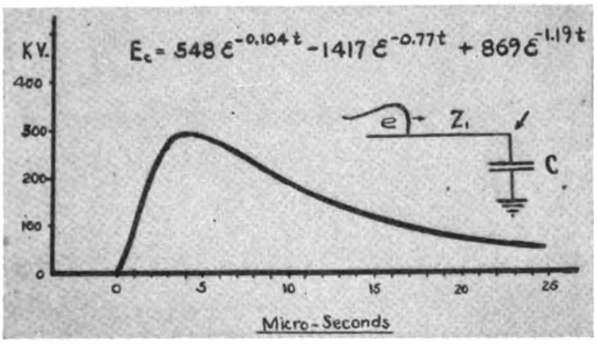

Fig. 9. Calculated Transformer Voltage When No Coil is Used

The importance of the surge impedance at the station is apparent. As Z_1 approaches zero, the transformer voltage approaches twice the voltage equation of the traveling wave. The impedance Z_1 governs the rate of voltage rise when a very steep wave is applied to a transformer. As previously shown, when oscillations occur, the surge impedance also affects the damping. Hence it is seen that the surge impedance of the line and transformer capacity play a noticeable part in protecting station equipment from very steep waves.

The two cases just analyzed—with and without the reactor—are the limiting cases of Fig. 10 when the resistance shunting the reactor is in one case zero ohms and the other case of infinite value. Choosing a value of resistance equal to 2000 ohms and computing the transformer voltage for the applied wave of Fig. 5, we determine the voltage curve of Fig. 11. The oscillation which occurred with no shunting resistance has practically disappeared, resulting in only a small increase over the open-circuit terminal voltage. This arrangement is therefore practically inoperative to such traveling waves and the 60-cycle duty of the reactor is unimpaired by the addition of the high parallel resistance. The general equation for the transformer voltage of Fig. 10 with an applied wave of $E\epsilon^{-bt}$ is

$$E_c' = 2E\left\{\frac{A}{\omega}\epsilon^{-kt}\sin\omega t + \frac{B}{\omega_o^2}\left[\epsilon^{-bt} - \frac{\omega_o}{\omega}\epsilon^{-kt}\sin(\omega t + \phi)\right]\right\} \tag{25}$$

where

$$A = \frac{1}{LC(R+Z)}$$

$$M = (ZRC + L)$$

$$B = A\,(R - Lb)$$

$$2k = MA$$

$$\omega = \sqrt{RA - k^2}$$

$$\omega_o^2 = (b^2 - 2kb + RA)$$

$$\tan\phi = \left(\frac{\omega}{k - b}\right)$$

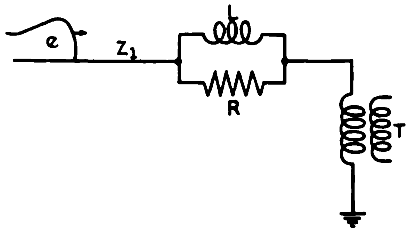

Fig. 10. Practical Arrangement in which the Reactor is Shunted with a Large Resistance

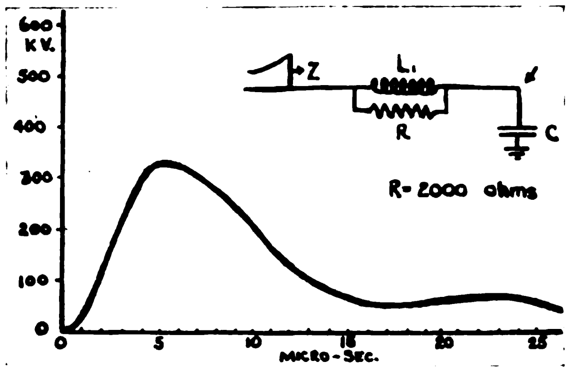

Fig. 11. Calculated Transformer Voltage When the Resistance of Fig. 10 is 2000 Ohms

We shall now consider the standard choke coil in place of the reactor in Fig. 3. Here the surge impedance of the line prevents the circuit from being oscillatory. The general equation for the transformer voltage with the exponential wave applied is

$$E_c' = \frac{2E}{\omega_o^2 LC}\left\{\epsilon^{-bt} - \frac{\epsilon^{-\left(\frac{Z}{2L}\right)t}}{2\omega}\left[n\,\epsilon^{\omega t} - m\,\epsilon^{-\omega t}\right]\right\} \tag{26}$$

where

$$\omega_o^2 = \left\{b^2 - \frac{Zb}{L} + \frac{1}{LC}\right\}$$

$$a = \left\{\frac{Z}{2L} - b\right\}$$

$$\omega^2 = a^2 - \omega_o^2$$

$$n = a + \omega$$

$$m = a - \omega$$

With the wave of Fig. 5 applied and taking L as 0.00004 henrys, the inductance of the choke coil shown in Fig. 1 of Mr. McEachron's paper, the resulting transformer voltage is

$$E_c = \left\{548\,\epsilon^{-0.104\,t} - 1288\,\epsilon^{-0.77\,t} + 742\,\epsilon^{-1.30\,t} - 2.8\,\epsilon^{-13.77\,t}\right\} \tag{27}$$

This voltage was plotted and found to give a curve which was practically identical with that of Fig. 9 and was therefore not redrawn. A comparison of Equation (27) with the equation appearing in Fig. 9 shows but minor difference. The corresponding oscillogram is shown in Fig. 13 of Mr. McEachron's article.

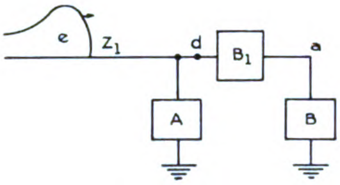

Fig. 12. Schematic Diagram of Terminal Apparatus Protected by a Lightning Arrester

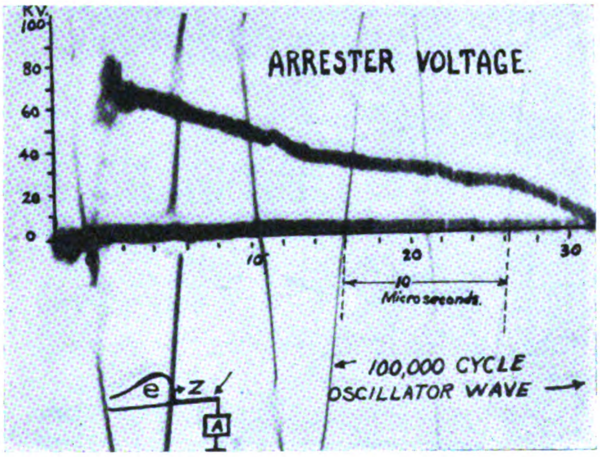

Fig. 13. Oscillogram of Arrester Voltage on the Application of the Open-circuit Wave of Fig. 5

ANALYSIS WITH THE LIGHTNING ARRESTER

The lightning arrester, being inherently a variable-resistance arrangement would indicate that its introduction into our circuit would so complicate the analysis as to be prohibitive in these few pages. This difficulty is overcome in the majority of cases by the use of an approximate solution which has been found to give very substantial results.

Consider the circuit of Fig. 12 where A is any lightning arrester whose characteristics are known. It is desired to determine the transformer voltage for the application of any traveling wave.

The approximate solution consists in first solving for the arrester voltage when the balance of the circuit is disconnected at d, and having determined this voltage, applying it to the balance of the circuit and solving for any voltage desired. This approximation is possible when a circuit carrying a small current is appended to a circuit carrying a relatively large current, which for the cases under consideration is always true. The current taken by the transformer is that necessary to charge its small capacity, and has previously been found to affect only the front of the wave (see Fig. 9). This small error is further compensated by the current accompanying the front of the wave, which passes the arrester before the voltage necessary to put the arrester in operation has been attained. The complete arrester voltage is readily determined by graphical methods, and has been found to check the oscillogram shown in Fig. 13, which was taken on a special arrester on the application of the open circuit wave of Fig. 5. In the latter this arrester characteristic is shown to the same scale as the applied wave.

The arrester voltage can usually be approximated by an equation of the form $E\,\epsilon^{-bt}$ where E is the voltage necessary to put the arrester into operation. For the particular case of Fig. 13 this equation is

$$E_A = 80\,\epsilon^{-0.05\,t} \tag{28}$$

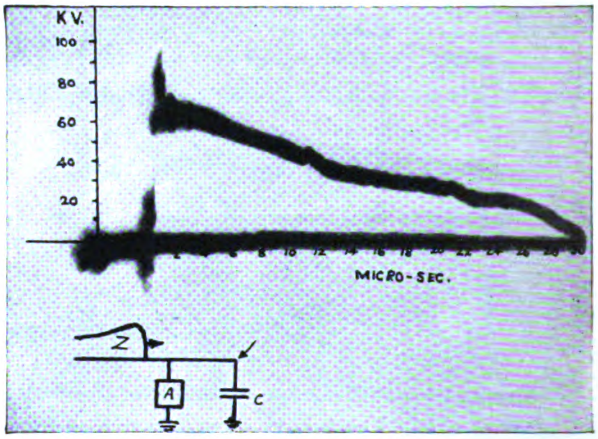

Fig. 14. Fast Wave Applied to Special Arrester and Capacitor

Hence, from this point on the analysis takes the same form as without the arrester; with this distinctive difference however, that, because of the local circuit formed by the arrester with the station impedance the resistance which gives rise to the damping of oscillations is no longer the surge impedance of the adjacent line Z_1. The laws controlling the determination of the proper resistance in each case are not known at the present time, but the factors controlling its value are (1) the type and size of the arrester as demonstrated by comparing the damping in Figs. 14 and 15 in Mr. McEachron's article (2) the location of the arrester with respect to the station equipment; (3) the surge impedance of the line, which must be considered in parallel with the arrester in an analysis of the local circuit, and (4) the impedance (B_1) which is placed between the arrester and the station impedance, as will now be shown in an analysis of the several cases.

Consider the case when $B_1 = 0$. Referring now to Equation (24) and changing Z to R the complete expression for the transformer voltage results. As R approaches zero the transformer voltage approaches the applied voltage which in this case is the arrester voltage (E_A). This point has been previously considered. The effective resistance of this circuit is therefore that resistance which accounts for the difference between the voltages of Figs. 13 and 14. It can only be said that this difference is negligible and that the effective resistance is very small.

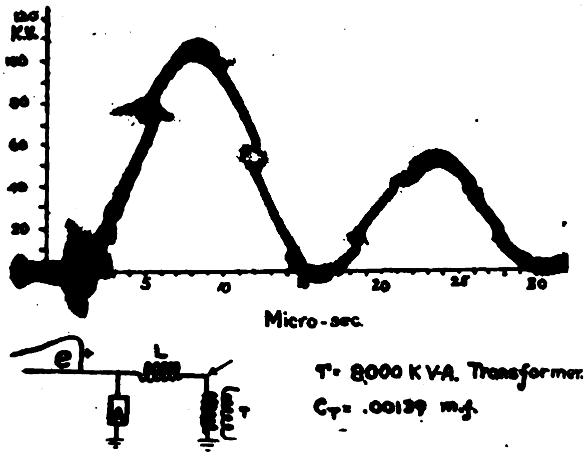

Fig. 15. Transformer Voltage with Fast Wave Applied to Special Arrester and to Transformer Through 3.88-millihenry Coil

(*Compare Fig. 5 of Mr. McEachron's article*)

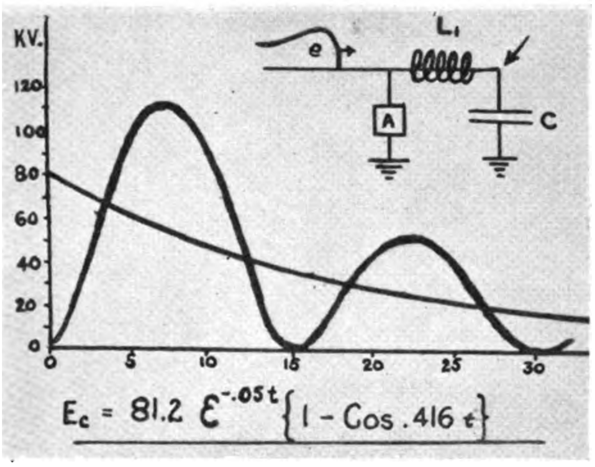

Fig. 16. Calculated Transformer Voltage Corresponding to the Field Test of Fig. 15

Consider the other extreme of placing between the arrester and the transformer the reactor whose inductance is 3.88 millihenrys, as used in the previous analysis. On inspection of the oscillogram taken under these conditions (Fig. 15), we see that the form of the equation is

$$E_c = K'\ \epsilon^{-bt}\ (1 - \cos \omega t) \qquad (29)$$

The condition necessary to bring this about is that a in Equation (14) becomes 0, hence from Equation (15)

$$Z = 2\ Lb \qquad (30)$$

The effective resistance for the case under consideration is therefore

$$R_o = 2 \times 3.88 \times 0.05 \times 10^4$$
$$R_o = 388 \text{ ohms}$$

Making the numerical substitutions in Equation (17) the transformer voltage becomes

$$E_c = 81.2\ \epsilon^{-0.05t}\ (1 - \cos 0.416\ t) \qquad (31)$$

This voltage is plotted in Fig. 16 and is found to satisfy not only the damping but the natural frequency and maximum voltage in agreement with the oscillogram. The arrester voltage may also be found in Fig. 16.

Returning to the choke coil, when no arrester was used the transformer voltage was found to be non-oscillatory. When the local circuit is formed with the arrester the resistance becomes very small, allowing an oscillation to take place as shown in Fig. 17. The effective resistance, as determined from the damping of this oscillation, is approximately 20 ohms.

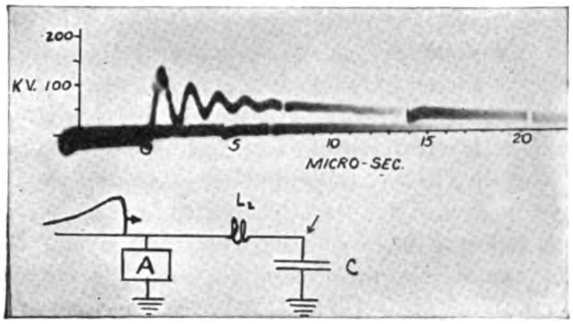

Fig. 17. Oscillogram of Transformer Voltage When the Standard Choke Coil is Placed Between the Arrester and the Transformer

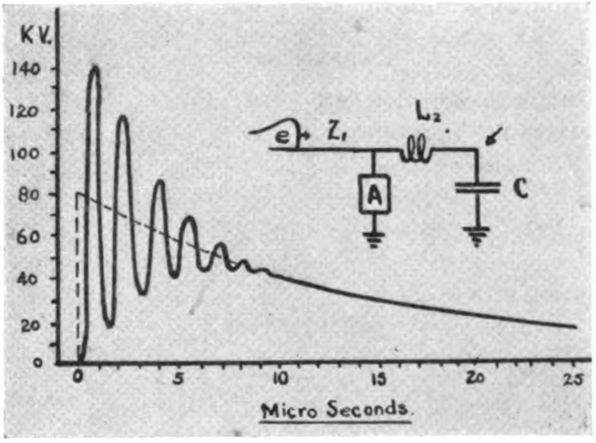

Fig. 18. Calculated Transformer Voltage When the Standard Choke Coil is Placed Between the Arrester and the Transformer (see Fig. 17). The axis of this curve is the transformer voltage without the choke coil (Fig. 14)

Placing the new constants in Equation (17) the transformer voltage takes the form

$$E_c = 80.1\ \{\epsilon^{-0.05t} - 1.002\ \epsilon^{-0.25t} \sin (4.215\ t + 1.52)\} \qquad (32)$$

This is plotted in Fig. 18 and should be compared with the oscillogram of Fig. 17. Because of the high natural frequency the maximum voltage is greater than in the case of the reactor in spite of the increased damping. From the foregoing data an empirical relation between R effective and L, the rest of this particular circuit (Fig. 16) being fixed, is

$$R = 1.85\ L^{0.645} \tag{33}$$

where L is in microhenrys.

When the transmission line extends past the terminal apparatus into a long line the analysis is just as readily obtained by applying Equation (11). In fact, the general equations hold for any type of terminal arrangement with any number of incoming or outgoing lines, neglecting the possibility of reflections from very short lines of only several miles in length.

Summary

Our increased knowledge of the types of waves found in practice,(1) together with a clearer understanding of the action of a mass of iron and copper to such traveling surges, as treated in the companion article by Mr. McEachron, has enabled this analysis to proceed in a very simple manner, obtaining results in agreement with field tests. The use of an equivalent lumped network in facilitating the solution, and the introduction of the approximate solution in connection with the protection of station equipment by lightning arresters has made it possible to place the problem upon a much firmer foundation.

The author is particularly indebted to Mr. McEachron and his staff for the helpful suggestions contributed toward this analysis.

APPENDIX

Using the notation previously given, the fundamental wave equations are:

$$e_1 = e + e_{r_1} \tag{1}$$

$$i_1 = i + i_{r_1} \tag{2}$$

$$e_{v_2} = Z_2\, i_{v_2} \tag{3}$$

$$e_{r_1} = -Z_1\, i_{r_1} \tag{4}$$

$$e = Z_1\, i \tag{5}$$

$$i + i_{r_1} = i_{v_2} + i_g \tag{6}$$

Referring to the general arrangement in Fig. 1, we have from Kirchhoff's Law that

$$e_1 - i_1\, B_1 = e_{v_2} + i_{v_2}\, B_2 \tag{7}$$

Substituting Equations (1), (2), (3), (4), and (5) in Equation (7) we have

$$i\left\{\frac{Z_1 - B_1}{Z_1 + B_1}\right\} - i_{r_1} = i_{v_2}\left\{\frac{Z_2 + B_2}{Z_1 + B_1}\right\} \tag{8}$$

however

$$i + i_{r_1} = i_{2v} + i_g \tag{9}$$

Solving Equations (8) and (9) simultaneously, we find that

$$i_{v_2} = \left\{\frac{2eB}{B\ (Z_1 + Z_2 + B_1 + B_2) + (Z_1 + B_1)\ (Z_2 + B_2)}\right\} \tag{10}$$

Now, returning to the closed circuit of Fig. 2 and solving for the current in Z_2 with the application of the voltage e, we have

$$i_2 = \left\{\frac{eB}{B\ (Z_1 + Z_2 + B_1 + B_2) + (Z_1 + B_1)\ (Z_2 + B_2)}\right\} \tag{11}$$

Hence

$$i_{v_2} = 2i_2 = \left\{\frac{2\ Z_{g(p)}}{Z_{o(p)}}\right\} e \tag{12}$$

Substituting Equation (3) in (12) we have

$$e_{v_2} = 2\left\{\frac{Z_2\, Z_{g(p)}}{Z_{o(p)}}\right\} e \tag{13}$$

Solving for the reflected voltage

$$e_{r_1} = \left\{1 - \frac{2Z_1}{Z_{(p)}}\right\} e \tag{14}$$

or

$$e_{r_1} = \left\{\frac{Z_{(p)} - 2Z_1}{Z_{(p)}}\right\} e \tag{15}$$

Similarly, the terminal voltage of the impedance B is

$$E_{ag} = \frac{Z_{2(p)}}{Z_2}\, e_{v_2} = 2\left\{\frac{Z_{2(p)}\, Z_{g(p)}}{Z_{o(p)}}\right\} e \tag{16}$$

The Testing of Transformers

PART III: HEAT RUNS

By G. CAMILLI
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General Electric Company

HEAT RUN

As in most electrical machines, the safe operation of a transformer depends essentially on the maximum temperature to which it is heated when under load. Temperature is of even more concern in a transformer than in other kinds of electrical machinery on account of its higher voltage of operation. An insulation which can withstand a considerable over-potential at ordinary temperature may break down when at a high temperature.

A transformer heats up in operation because of the losses in its core and windings. The core loss depends on the flux in the iron, or what is the same thing (for a given frequency) on the applied voltage, and is practically independent of the load. The copper loss is directly proportional to the square of the current flowing through the windings. Therefore, in order to determine the temperature rise in a transformer, the unit must be subjected to its full rated voltage and full-load current simultaneously. Various methods of loading are used, of which the most common are:

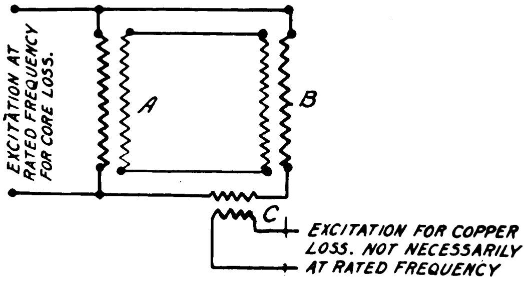
EXCITATION AT RATED FREQUENCY FOR CORE LOSS.
A
B
C
EXCITATION FOR COPPER LOSS. NOT NECESSARILY AT RATED FREQUENCY

Fig. 18. Full-load Heat-run Connections for the Opposition Method of Testing Two Single-phase Transformers (*A* and *B*). The core loss of both transformers is supplied from one source, and the copper loss from another

(a). Dead Load

Small-capacity transformers may be tested under actual load conditions by loading on a lamp bank, water box, rheostat, etc. This method is expensive when a large amount of power is required.

(b). Loading Back

When two similar transformers are available, one transformer can be loaded on the other and the second connected back to the source of supply. By this method the only power required is that necessary to supply the losses in both transformers.

This so-called "loading back," or more appropriately designated "stray power" or "opposition," method is the one used in testing not only transformers but generators and motors. The method may be used with any size of transformers.

The connections for an opposition heat test on two transformers are shown in Fig. 18 in which either *A* or *B* or both are the transformers under test. Their low-tension windings are connected in parallel to the power supply and their high-tension windings are connected in opposition to each other. If the transformers are identical, the excitation from this power source causes no current flow through the high-tension windings.

If now a full-load current should be made to circulate in the windings, the transformers will be under heating conditions that are identical to those of full load. As this circulating current gives rise to copper loss only, the current need not be of the rated frequency of the transformer. Even a direct current may be used for the purpose, provided the eddy-current and stray losses of the transformer are not appreciable. However, on account of the fact that practically all power transformers have appreciable eddy-current and stray losses, it is desirable to hold the load current at approximately rated frequency when making heat runs. A convenient method is to open one of the circuits, preferably that of the low-voltage winding, and to introduce there a comparatively low-voltage source of alternating current of about the rated frequency. This auxiliary source is shown in Fig. 18 in the form of a transformer *C*.

By adjusting the voltage of this source, full-load current can be made to flow in the primaries of the transformers under test; this current induces full-load current in the secondaries which therefore need not be opened for separate loading. This method is particularly convenient to apply to transformers that are wound for comparatively high voltage.

In this test the transformers are under actual load conditions as far as the losses and heating are concerned and, at the same time, the testing operation draws from the source of supply only that amount of energy which is sufficient to overcome the losses.

A transformer should always be interposed between the supply alternator and the transformers under test in order to avoid high potential on the switchboard and to prevent the possible breaking down of the insulation of the alternator.

Where a large number of small similar transformers are to be loaded at the same time, their primary windings may be connected in parallel and their secondaries may also be connected in parallel, or (as in Fig. 19) the secondary of one transformer in a group may be paired with that of one of the opposition group independently of the secondaries of the other transformers in the same group.

When there are three single-phase transformers to be tested, a scheme employing three-phase excitation with single-phase loading may be used, as outlined in Fig. 20.

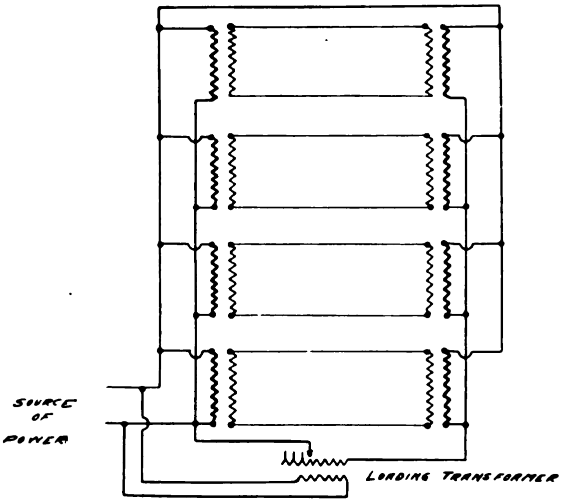

Fig. 19. Full-load Heat-run Connections for an Even Number of Small Similar Transformers Arranged in Two Opposing Groups; Here, Four Against Four

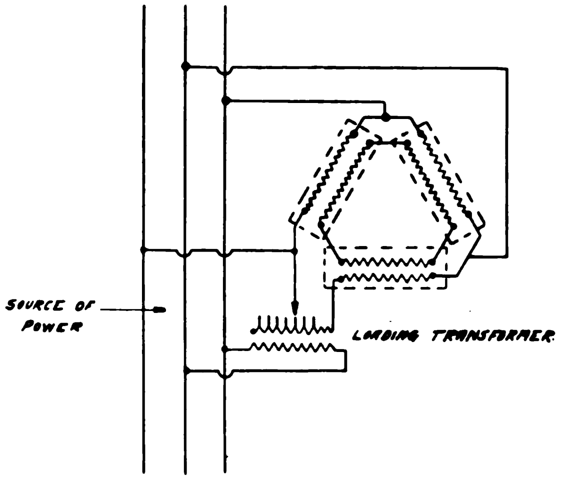

Fig. 20. Full-load Heat-run Connections for Testing Three Single-phase Transformers by a Method Employing Three-phase Excitation and Single-phase Loading. The diagram applies also to the heat-run test of a delta-delta three-phase transformer by the open-delta method

(c). Cascade Loading

If two switchboards excited from a common bus of proper voltage are available and one of the boards is equipped with an induction or other type of regulator, one or more transformers may be connected between them and a flow of normal load current obtained by adjustments of the regulator. This method can be used only within the capacity of the regulator.

(d). Compromise Load

Owing to possible limitations of available apparatus for making the heat test, and on account of the peculiarity of some designs, it may be found impracticable to imitate actual load conditions. Under such a circumstance, compromise runs may be made by alternating open-circuit tests at rated excitation with short-circuit tests at rated current circulated in the windings. This method is used only for the purpose of determining whether the transformers will exhibit trouble under load conditions.

Sometimes approximate heat runs are made on single transformers by either an overload short-circuit run or an over-excitation open-circuit run, or by an alternation of the two. These approximate runs give oil temperatures only, and must be very carefully performed to avoid injuring the core or windings by excessive local heating.

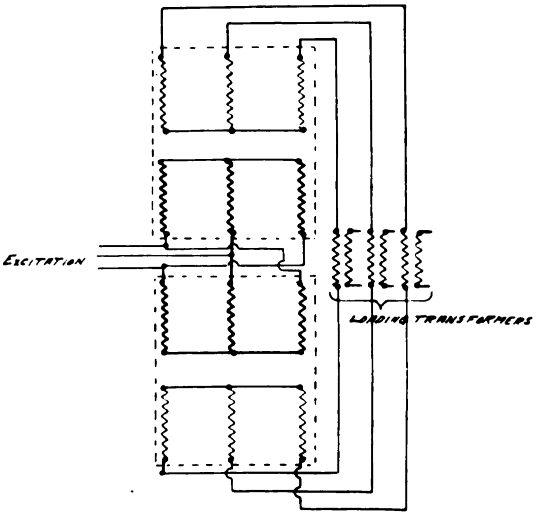

Fig. 21. Full-load Heat-run Connections for Testing Two Y-Y Three-phase Transformers by the Opposition Method

Choice of Method

Single-phase Transformers

When only one transformer is available. Methods (a) or (c) may be used.

When two transformers are available. In general, Method (b) should be used.

Three-phase Transformers

When only one transformer is available and it has delta-delta windings. Methods (a) or (c) may be used on small-capacity transformers.

Modification of Method (b)

A three-phase transformer may be loaded by using Method (b) when the high-voltage and low-voltage windings are capable of being connected delta-delta. One of the deltas must be opened (see Fig. 20) and a suitable single-phase current introduced at that point, while three-phase excitation is applied to either one of the groups of windings in order to supply the no-load loss and the exciting current. The load current circulates within the delta and is entirely independent of the three-phase excitation.

This method, however, is not recommended for three-phase core-type transformers, on account of the fact that excess loss may be obtained, particularly in the tank, because the leakage flux is all in one direction in the three phases.

Delta-Y or Y-Y Transformers

Whenever possible, the neutral of a Y connection should be disconnected and the transformer loaded by using the connections just described.

Where this is not possible, Fig. 21 shows a method of three-phase excitation and three-phase loading that is very convenient. This method, although not very often used, is the most accurate method of loading for it gives balanced load and voltage conditions as in service.

If in this method it is found necessary to apply excitation and load current to the same windings, the excitation should be applied to the midpoints of the loading-transformer windings so as to maintain balanced conditions on the transformers under test.

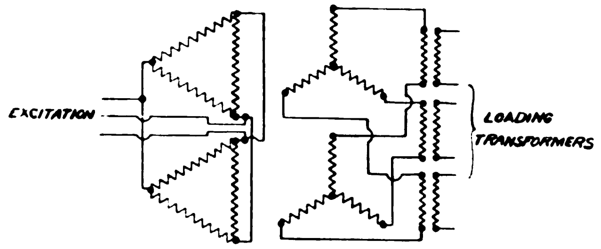

Fig. 22. Heat-run Connections for Two Delta-Y Three-phase Transformers in which the Load Current Supply is Impressed on the Y Windings

The advantages of this method are:

(1). No temporary internal connections required

(2). Service voltage conditions duplicated

(3). Balanced loading of the two transformers accomplished.

The disadvantages are:

(1). Complex connections

(2). A three-phase loading transformer is required.

In Figs. 22, 23, and 24 are illustrated other more frequently used methods for testing delta-Y transformers. In that of Fig. 23 the high-tension delta windings of the two transformers are first opened and then connected in series with each other and the loading transformer. This method is not suitable for transformers of high reactance owing to excessive load losses. For transformers of the latter type, the method in Fig. 24 must be used in order to obtain balanced service conditions. It is sometimes found necessary to excite the same side as that into which the load is introduced, in which case the excitation should be applied to the mid-points of the loading transformer in order to maintain balanced conditions on the two transformers.

The scheme of connections for a heat run on standard Y-Y transformers is shown in Fig. 25. This method entails the opening of the Y connection of the high-voltage side and the reconnecting of the windings in series. The method gives satisfactory results and is very commonly used. The advantages are simplicity of connections, balanced conditions of the two transformers, single-phase loading, and three-phase excitation. If the transformers have high impedance, the method has the disadvantage that the voltage across the loading transformers will be high, being approximately equal to the sum of the impedance voltages for the six legs. There is also the disadvantage of temporary internal connections. Furthermore, the method is not suitable for transformers of high reactance owing to excessive load losses (eddy-current losses in the conductors) which, owing to the series method

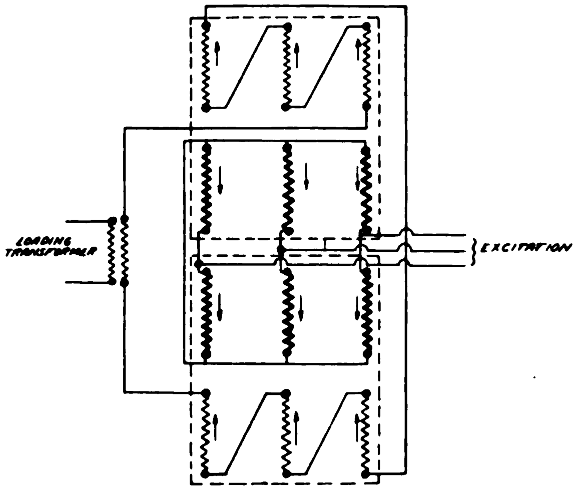

Fig. 23. Heat-run Connections for Two Delta-Y Three-phase Transformers in which the Delta Windings Are Opened at One Point and Then Connected in Series with Each Other and the Loading Transformer

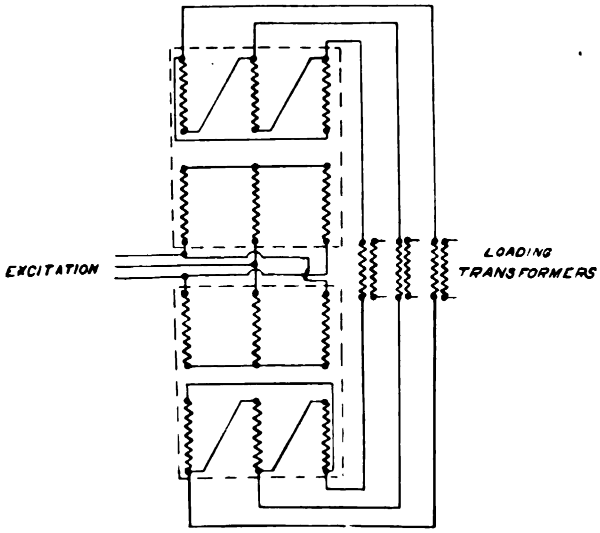

Fig. 24. Heat-run Connections for Two Delta-Y Three-phase Transformers in which the Delta Connections Are Retained and Three Separate Transformers Employed to Circulate the Current Load

of loading, will be higher than the true losses. In such cases it is much better to use the scheme shown in Fig. 21.

Methods of Temperature Determination

The fundamental methods of measuring temperature are:

(1). The thermometer method
(2). The resistance method.

The Thermometer Method

Because mercury is a metal, thermometers of the mercurial type should not be used inside of transformers or anywhere that they invite a short circuit or a breakdown in the insulation by reason of their presence, intact or broken. For this reason all temperature measurements by thermometer, except those of outside tank temperature, etc., should be made by thermometers of the alcohol type.

The surface temperature of iron or alloy parts surrounding or adjacent to leads carrying large current, and the temperature of the caps of the terminals or of the leads carrying this current, should be read at the end of the heat run immediately after shutdown. Top-oil temperature should be read every hour by a thermometer which has the bulb immersed two inches in the oil.

When it is not convenient to read a thermometer each hour, a thermocouple may be placed in the oil near the thermometer and the thermocouple read every hour. In such cases, however, the thermometer should be read every three hours and also at the end of the heat run. Also, the thermometer and thermocouple readings should approximately check each other.

The Resistance Method

This method consists in calculating the average temperature of the windings from measurements of the increase in resistance of the windings as determined by readings of voltage drop across them, when cold and hot, for the same direct-current flow.

The necessary measurements may be made in either of two ways:

(1). Potentiometer method
(2). Voltmeter-ammeter method.

Of these two, the first is generally used when the drop to be measured is one volt or less. When using the second, the current to be measured should be high enough to give a good reading on the voltmeter, but in any case should not be more than 15 per cent of the rated current of the winding. For very low resistances, the voltmeter-ammeter scheme is not desirable because of the very large current required to produce a voltage that can be accurately measured.

The Wheatstone bridge is not suitable for such an application because its resistances include leads and contacts which are a large proportion of the total resistance. The potentiometer avoids these errors and it is therefore preferable for measurements of low resistances.

In using the voltmeter-ammeter method, care must be taken to avoid including the resistances of leads and contacts. This can be done by carrying separate leads to the voltmeter and to the ammeter from the transformer terminals.

When applying the direct current, an induced counter-e.m.f. lowers the voltmeter reading for a time. This e.m.f. gradually disappears but is objectionable because it delays the taking of the voltmeter readings. It can be made to decrease more rapidly by first raising the current to a value about 10 or 15 per cent in excess of that desired and then bringing it down slowly.

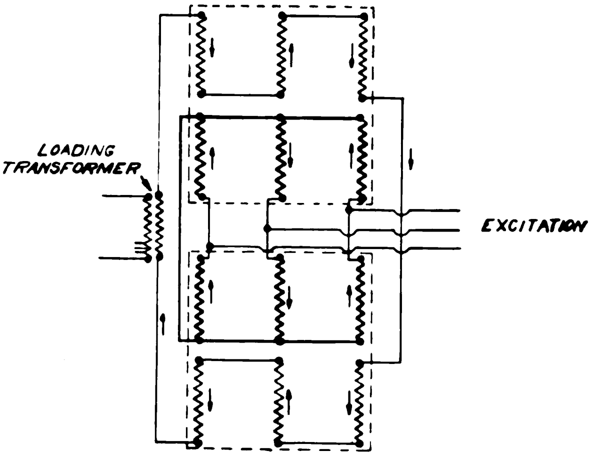

Fig. 25. Heat-run Connections for Testing Two Y-Y Transformers by an Opposition Method in which the Windings of Each Y Are Disconnected and Arranged in Series for Loading

The fundamental relation between the rise of temperature and the increase of resistance of copper may be expressed thus:

$$R_h = R_c \left\{ 1 + a\,(t_h - t_c) \right\} \quad (3)$$

where

R_h = hot resistance (at temperature t_h deg. C.)
R_c = cold resistance (at temperature t_c deg. C.)
a = temperature coefficient at zero deg. C. = 0.00427

For use in slide-rule calculation the following formula is more convenient:

$$\frac{R_h}{R_c} = \frac{234.5 + t_h}{234.5 + t_c} \quad (4)$$

Measurement of the Cooling-medium Temperature

The following types of transformers require consideration:

(1). Self-cooled transformers
(2). Water-cooled transformers
(3). Air-blast transformers.
(4). Forced oil transformers.

Self-cooled Transformers

If the room temperature is kept constant throughout a heat-run, this actual temperature is the effective reference base. Mercury thermometers placed in the air or in small oil cups are satisfactory for the determination of this temperature.

In the case of varying room temperature, the best method of correcting for errors due to uncertainty of the effective room temperature is the use of some device which produces a lag behind the air temperature corresponding in degree and in phase with the lag of the heated transformer. The most satisfactory device which has been found is another transformer of the same design, preferably a duplicate of that under test. This second transformer should of course be maintained as an idle unit but subjected to the same cooling medium as the transformer under test. The effective temperature of the cooling medium is then the average temperature of the idle unit, which may be determined by thermometer or by measuring the resistance of the windings. It is considered best, however, to use resistance measurements merely as a check on the oil temperature as observed by thermometer.

Water-cooled Transformers

The case of water-cooled transformers presents two cooling mediums for consideration. However, since the amount of heat taken away by radiation and convection from the surface of the tank is negligible compared to that removed by the cooling water, no correction need be applied for the difference between the temperature of the surrounding air and that of the cooling water. In any case it is nevertheless desirable that the water temperature be within 5 deg. of the room temperature, and at 25 deg. C. if possible, the temperature being measured at the intake of the cooling coil.

Air-blast and Air-cooled Transformers

These types of transformers follow changes in air temperature much more closely than do the oil-immersed types, because their thermal capacities are much smaller. The ingoing air temperature is measured directly and is taken as the effective base, precautions being taken to guard against sudden fluctuations.

Forced Oil Transformers

These may be of the water-cooled type or of the air-cooled type.

In either case the reference temperature base is that of the cooling medium, *i.e.*, the temperature of either the ingoing cooling water or that of the cooling air.

Measurement of Cold Resistance

Thermometers should be placed in direct contact with the windings or coils, or in the ducts between the coils, at least one-half hour before the first readings of resistance are taken. Sufficient readings of temperature and resistance should be taken to determine their exact value.

In making resistance measurements, the readings should be taken as quickly as is consistent with accuracy and the current should be small enough to avoid any appreciable heating of the windings.

The resistance to be measured is generally known approximately, so that the potentiometer can be set fairly close to the correct point beforehand. The time taken to adjust to the correct settings can therefore be made very short, which is quite necessary when measuring the resistance at the end of the heat run.

When an idle unit is used the *cold resistance* R_c of the *hot transformer* should be determined as follows:

$$R_c = R_f \frac{T_s}{R_s}$$

in which

R_f = resistance of idle unit at the end of the heat run

R_s = resistance of idle unit before the heat run.

T_s = resistance of hot transformer before the heat run.

The ratio $\frac{T_s}{R_s}$ should be based on the same temperature.

Measurement of Hot Resistance

The hot resistance measurements should be made by the same method as described for the cold resistance measurements.

The resistance of the high-voltage winding should be measured as soon as possible after shutdown. That of the low-voltage winding should be measured as soon as possible after taking the readings on the high-voltage side. If all the resistance readings cannot be completed within five minutes the heat run should be resumed until normal temperatures are again obtained, after which the remainder of the readings should be taken.

Both the values of resistance and time required to take each reading after shutdown should be recorded in order to calculate the maximum value of temperature reached by the windings.

The thermal capacity of the coils being much less than that of the other parts, the windings cool initially much faster than the other parts of the transformer.

The rate of cooling of the windings may be calculated as follows:

Before the load is taken off, the windings are at a constant temperature rise above the oil so that the rate at which they are giving out heat is the same as the rate at which energy is being put into them, or in other words, that necessary to supply the copper loss. This rate continues for a short period after the load is taken off. The thermal capacity of a pound of copper is about 177 joules. Then, if the coils are giving out heat at the rate of one watt per pound (0.45 kg.), one joule will be lost during the first second after shut down. This will cool the coil 1/177th of a degree in the first second and 60 times this amount or 0.342 deg. in the first minute. At three watts per pound the cooling in the first minute would be three times the foregoing figure, or approximately 1.04 deg. These values will be modified to some extent by the fact that the insulation of the coil has a certain thermal capacity, thus increasing the total heat and decreasing the rate of cooling.

The rate of fall of temperature decreases as the temperature of the coil approaches that of the oil, and becomes equal to that of the oil when the oil temperature is reached. The curve of temperature against time is logarithmic in shape, the rate of cooling at any point being proportional to the rise above the base or oil temperature.

The total time of cooling varies with the design, but ordinarily it is between 30 and 60 min. Of this period the major concern is with the first minute or two, and during that interval there is very little change in the rate. If the watt loss per pound of copper is known, an approximate correction may be made with the aid of the values given on page 690. A convenient method which gives fairly accurate results is to take several readings of resistance over a period of 5 or 6 min. so as to be able to plot the cooling curve and then project the curve backward to determine the initial resistance. This method has the disadvantage that it allows the transformer to cool considerably and thus prolongs the heat run in case any further measurements are desired, such as the rise by resistance of the other winding.

The rate of cooling of windings in air-blast transformers is lessened considerably if the air is shut off simultaneously with the load.

In fact, it is quite often found that the thermometers on the coils indicate an increase in temperature for the first few minutes. This change probably results from the shutting off of the air supply leading to an equalization of temperature throughout the coils, thus reducing the higher and increasing the lower temperatures.

Exploring Coils and Temperature Indicator

The rise by resistance of the winding shows only the average temperature of the winding. It is sometimes considered desirable to ascertain the temperatures at points where it is suspected that the values will be considerably above the average. This can be done by means of small exploring coils.

It is also desirable in some cases to determine the temperature of the windings without disconnecting the load. This may be accomplished by means of a small exploring coil which measures a local temperature or by means of a resistance coil located in the upper part of the transformer winding. When desired, transformers up to 30,000 volts can be furnished with such a resistance unit wound in it so that the internal temperature of the winding may be very closely determined by means of a temperature indicator, the scheme of connections being as shown in Fig. 26.

Details That Should be Observed in Performing a Heat Run

Self-cooled Transformers

If the transformer has a conservator, this should be filled to the proper level.

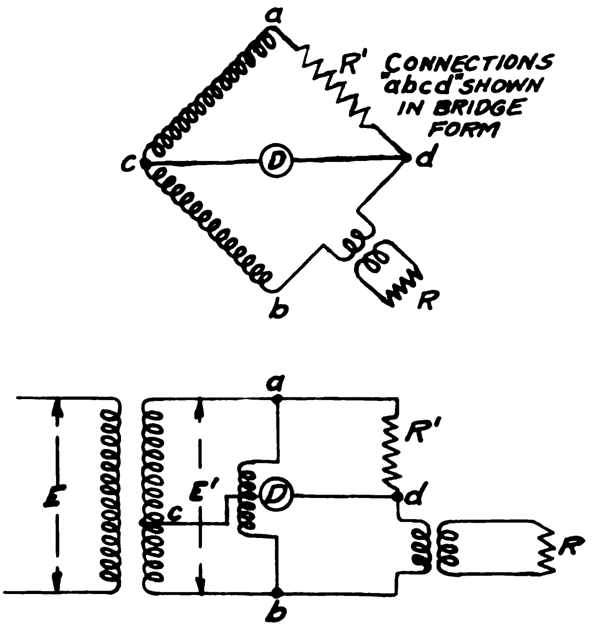

Fig. 26. Simplified Connections of Alternating-current Temperature Indicator for Use in Conjunction with Exploring Coils

For reading top-oil temperature, a thermocouple is passed under the manhole cover so as to project about four inches below the edge of the manhole. Tape should be wrapped around the thermocouple lead where it passes over the edge of the manhole to prevent the lead being cut when the manhole cover is bolted down.

The readings are to be taken each hour.

If there is a third transformer, it is used as an idle unit for measurement of the base temperature. It should be filled to the same level as the test units and should be placed at least three feet from any source of heat.

Two thermometers should be placed on opposite sides of the outside surface of the tank of the idle transformer in a position approximately midway between the top and bottom of the coil stacks. During the heat run, the lines used for resistance measurement should be left connected to the high-voltage winding of the idler, as it may be desirable to check the idler resistance during the heat run.

If a third unit is not available for an idler, any transformer or spare tank of approximately the same dimensions as the transformers being tested may be filled with oil and used as the idler. Any unit that is used for an idler should be located at the same level as the units on the heat run.

Small self-cooled transformers are usually started with a small overload to increase the rate of heating. When the oil rise is within one degree of the expected rise, the load should be reduced to normal.

Water-cooled Tra[illegible]ers

No idler should [illegible]sed in connection with heat runs on water-cool[illegible]ts.

The top-oil tem[illegible]re is read by a thermocouple. If the transf[illegible] have conservators, they need not be filled into [illegible]ervator for the heat run but should be filled to [illegible] three inches of the cover.

The oil temperature rise is the difference between the top-oil temperature and the ingoing-water temperature.

Heat runs on this type of unit should be started without flow of cooling water to increase the rate of heating temporarily. The water should be turned on however when the oil rise is within five degrees of the expected value.

The water flow in each pipe should be kept so adjusted that at all times a temperature difference of 10 deg. C. is maintained between the ingoing and outgoing water.

After the heat run is completed, a pressure gauge should be inserted at the transformer inlet water valve and readings taken of the pressure necessary to force through the cooling pipes the same amount of water as was recorded in the final reading for the heat run. At the same time the water flow of *each* pipe should be measured with a measuring can. A record should be made of the water pressure and the time required to fill the measuring can and from these data the total flow for all pipes should be calculated.

Air-blast Transformers

The wiring for the test should be arranged as explained in the general description of the heat run.

Mercury thermometers are to be placed at the top, middle, and bottom of each joint in the core laminations on one end and one side of the transformer.

At least one spirit thermometer should be placed in each high-voltage and in each low-voltage group of coils. If the coil group is of more than four coils, several thermometers should be placed in it. The thermometers should be located so that the bulbs will be down in the air ducts and touching the coils. During the first few hours of the heat run, the location of the coil thermometers should be changed from time to time in an endeavor to locate them finally at the hottest portion of the coil groups.

The ingoing and outgoing air temperatures should be read by several thermometers located at various places directly in the air path, and the average readings recorded.

The specified pressure and volume of air should be maintained during the test.

Final Temperature

When the heat run is shut down for resistance measurements, the coil thermometers and the temperature indicator coils (if any) should be read continually in rotation until the temperature begins to fall. The highest temperatures are then to be recorded as the final temperatures.

Temperature Rise

By temperature rise is meant the final observed temperature reached in the heat run minus the reference or ambient temperature.

Temperature Rise Corrections

Corrections should be applied to the observed temperature rise under the following conditions:

(1). When the guarantee is based on the rise at the instant of shutdown.

(2). When the observed rise is based on an ambient temperature different from the standard of reference.

(3). When the guaranteed temperature rise is based on an altitude which is appreciably different from that at which the test is made.

Unless a given guarantee is for a special ambient temperature, the desired ambient temperature should be 25 deg. C. for water-cooled transformers and 40 deg. C. for self-cooled transformers.

Correction for Cooling of Winding After Shutdown (4)

Since a drop in temperature occurs in a winding between the instant of shut-down and the time of measuring the hot resistance, a correction should be applied to the temperature determined from this measurement so as to obtain as nearly as practicable the temperature at the instant of shut-down. This correction may be determined approximately by making a series of resistance measurements and from these calculating and plotting a time-temperature curve which is extrapolated [illegible] shutdown.

Other permiss
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(4) Taken from A.I.E.E.

measurement is taken as given in the following table:

Time in Minutes	Factor
1	0.19
1½	0.26
2	0.32
3	0.43
4	0.50

For intermediate times the values of the factor may be obtained by interpolation.

When the copper loss, measured by wattmeter, does not exceed seven watts per pound, an arbitrary correction of 1.0 deg. C. per minute may be used, provided the time elapsed between the instant of shutdown and the measurement of the hot resistance does not exceed four minutes.

For determining the copper loss in watts per pound, the total loss in both windings as measured by wattmeter shall be apportioned between high and low-voltage windings in the ratio of their respective I^2R losses.

(*b*). *For Air-blast Transformers.* Whenever the temperature is measured by thermometers no correction should be made for the time elapsed between the instant of shutdown and the reading of the thermometers.

Correction of Observed Temperature Rise for an Ambient Temperature Different from That of the Standard of Reference

(*a*). *Air-blast Transformers.* Air-blast transformers shall have a correction applied to the observed temperature rise of the windings, when the temperature of the ingoing cooling air differs from 40 deg. C. because of the difference in resistance. This correction should be applied as follows: Corrected Temp. Rise = Observed Temp. Rise $\times \frac{274.5}{234.5+\theta}$ where θ is the ingoing cooling air temperature.

(*b*). *Oil-immersed Transformers.* Unless the ambient temperature is specified, the desired ambient temperature is assumed to be 25 deg. C. for water-cooled transformers and 40 deg. C. for self-cooled transformers.

Due to the fact that the viscosity of the cooling oil increases with decrease in temperature, the temperature of the top oil and of the winding is higher than it should be when the ambient temperature during the heat run test is below the standard of reference and is lower if the test ambient temperature is higher than the standard of reference. Correction factors may be obtained from the transformer manufacturer for the particular type of oil used.

Correction factors are appreciable for oils having high viscosity and high freezing temperature, and are negligible for oils of low viscosity and low freezing temperature.

For instance, for No. 10-C Transil oil (which is standard for all G-E transformers) a difference of 20 deg. C. rise in the ambient temperature makes only one degree difference in the rise of coil temperature above ambient.

Correction for Altitude

When the guaranteed temperature rise is based on operation of transformers at altitudes higher than 1000 meters (3300 ft.), the correction should be made in accordance with Section 13 of the 1925 A. I. E. E. rules, quoted as follows:

Altitude (*a*). Standard apparatus tested at an altitude not exceeding 1000 meters: Apparatus rated in accordance with these standards may be tested at any altitude not exceeding 1000 meters (3300 ft.) and no correction shall be applied to the observed temperature rise.

(*b*). Standard air-cooled apparatus tested at an altitude greater than 1000 meters: If the test is made at an altitude greater than 1000 meters it shall be assumed that the temperature rise at any altitude less than 1000 meters will be the temperature rise observed at the higher altitude reduced by 4/10 of one per cent in the case of oil-immersed or natural-draft apparatus and by one per cent in the case of air-blast apparatus for each 100 meters (330 ft.) by which the altitude at which the apparatus is tested exceeds 1000 meters.

NOTE.—The term "temperature rise" here applies to the rise of temperature of the windings as measured by resistance. The term "oil-immersed apparatus" refers only to self-cooled types. No correction is required in the case of water-cooled transformers.

Example: Assume that self-cooled transformer tests 55 deg. C. winding rise at 19,800 ft.

$$\text{Correction} = \frac{19{,}800 - 3300}{330}\ (0.4 \text{ per cent}) = 20 \text{ per cent.}$$

At Pittsfield (altitude 1010 ft.), it would test $55\left(1-\frac{20}{100}\right) = 44$ deg. C.

Conversely, if it tested 44 deg. C. at Pittsfield it would test $\frac{44}{\left(1-\frac{20}{100}\right)} = 55$ deg. C. at 19,800 ft. altitude.

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Lightning

PART II

Cathode-ray Oscillograph Measurements—Research on Transmission Lines—Value of Ground Wire—Coördination of Insulation—Lightning-proof Lines

By F. W. PEEK, Jr.
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General Electric Company

A GREAT amount of important field work has been done since 1927. This work might be divided into two classes: a study of lightning strokes, the clouds producing them, the effects of the strokes on rods, etc.; and a study of lightning as it appears on transmission lines whether by direct hits or by induction.

Some of the most important measurements will be described briefly:

Cathode-ray Oscillograph Measurement of Natural Lightning Waves and of the Time Required for a Cloud to Discharge

Perhaps the most interesting results were the oscillograms of natural lightning. A portable cathode-ray oscillograph of the DuFour type developed by the General Engineering Laboratory of the General Electric Company made this possible. In order to make proper use of the oscillograph, it was necessary to devise a means of establishing the cathode beam and the sweeping circuit and to have the complete set-up connected to the line when the lightning wave reached it. With the equivalent "switching circuit" developed for this, the complete operation was accomplished in about one microsecond, *i.e.*, one millionth of a second.

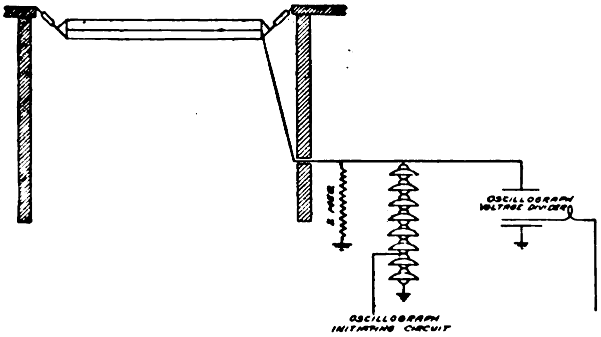

Fig. 37. Method Employed in Measuring Natural Lightning

Part of the wave front would accordingly be lost unless special means were taken to prevent it. One way to accomplish this is to side-track the wave around a loop about 1000 ft. (305 meters) long, requiring about one microsecond to travel it, and take it coming back. However, the results so far indicate that this refinement will usually not be necessary. The actuation of the oscillograph is done by means of spark "switches" controlled by the lightning surge. Connection to the line was made by an insulator potentiometer.

Measurements were made on short horizontal antennas and on actual transmission lines. The antenna measurements were made at Pittsfield while the transmission line measurements were made on the 220-kv. lines of the Pennsylvania Power & Light Company in coöperation with their engineers. This work is being extended in 1929 to include investigations on lines of the Ohio Power Company and the Consumers Power Company.

Measurements Made on Antennas

In the Pittsfield measurements the antennas consisted of three parallel wires 120 ft. (36.6 meters) long and 40 ft. (12.2 meters) above ground. The wires were grounded through a two-million ohm resistance and connection to the oscillograph was made as in Fig. 37. With this arrangement the lines assume a potential opposite to that of the cloud when the lightning discharge takes place. Since the charge cannot move along this short line, but must be dissipated by leakage, the potential of the conductors rises at a rate and to a magnitude dependent upon the collapse of the cloud field. The time for this conductor voltage wave to reach maximum is thus a measure of the time required for the cloud to discharge. Fig. 38 shows two of the four antenna waves obtained. The wave fronts are of the order of one to two microseconds. The induced voltage crests on the antennas were from 50 to 75 kv. The storm clouds in each case were at least a mile away. Such wave measurements, indicative of actual cloud discharges, are very helpful in determining the shape of surges themselves on transmission lines.

Lightning Wave Measurements Made on 220-kv. Transmission Lines

One very good record was obtained of a traveling wave on the 220-kv. transmission line, and is shown in Fig. 39. The front of this wave practically reaches its maximum in five microseconds, decreases to half value in 20 microseconds, and reaches zero in 40 microseconds. The oscillating ripple is apparently due to a local flashover and is not really part of the original wave. A reproduction of this wave by the laboratory lightning generator is also shown in Fig. 39. The effects of the wave are very similar to the standard waves of Figs. 5 and 6 (Part I), and the impulse ratio for insulator sparkover corresponds to those determined by the surge recorder readings. This oscillograph study of lightning surges on actual lines is being continued on a greater scale during 1929.*

Other Research on Transmission Lines

During the past few years a number of the operating companies in collaboration with the manufacturing companies have obtained some very important measurements, particularly of lightning voltages on transmission lines.⁽⁵⁾ These measurements were obtained with the klydonograph or with the surge-voltage recorder connected at various points along the transmission lines.

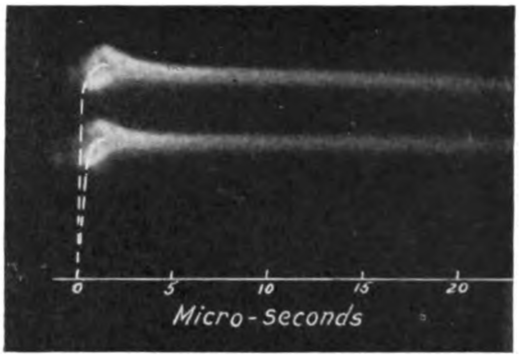

Fig. 38. Oscillogram of Natural Lightning Made on Short Lines at Pittsfield in 1928

Voltage, Polarity, Wave Shape, and Limitation of Voltage

The surge-voltage recorder measures the maximum of the wave and indicates the polarity. By comparing the insulator sparkover voltage resulting from lightning with the 60-cycle sparkover voltage, the impulse ratio is obtained. The impulse ratio gives a good indication of the effective duration of the wave. The lightning voltages causing sparkover on transmission lines in various sections of the country give an impulse ratio of the order of two. Waves giving such ratios are shown in Figs. 5 and 6. The crosses for 4, 10, and 14-unit insulator strings in Fig. 8 represent the average voltage (crest) of insulator sparkovers caused by natural lightning and measured by surge voltage recorders. The maximum impulse ratio observed was approximately 2.7.

In the many measurements made, the very low voltages necessarily induced were mostly positive, indicating a negative cloud. Most of the excessively high voltages, probably direct strokes, were negative, also indicating negative clouds. A few high positive and low negative voltage surges indicated that some clouds are probably positive. The general indications were that the waves were non-oscillatory, or very highly damped.

Measurements on different lines in various parts of the country and on the 220-kv. lines of the Pennsylvania Power and Light Company with 14 and 4 units insulation show that the maximum lightning voltage on transmission lines is limited to the lightning sparkover of the insulators. Measured points are shown by crosses in Fig. 8.

Attenuation

Surge-voltage readings along transmission lines show how the traveling wave attenuates or decreases in voltage. The attenuation per mile has been shown to vary as the square of the voltage. A wave cannot travel far at very high voltage.

Direct Strokes

Fig. 40 illustrates the method used in studying the effects of direct strokes. Photographs showed certain office buildings struck. An examination was made to see if any of these hits fell within the protective cone of other buildings as established by former laboratory tests.⁽¹⁾ It was found that they were in agreement with tests on models made to scale. The tests on models indicate that a rod on a flat plane protects a circular area around it. The radius of this area varies with the ratio of the height of cloud to height of rod as shown by the test results given in Table I. Large areas may be protected by several rods arranged so that their respective protective areas overlap. Projections above ground must be below a line drawn from the top of the rod to the limit of its protective radius. For a given condition this line is the arc of a circle passing through the rod tip and tangent to the ground level, its center being at an assumed minimum cloud elevation. However, where the rod is low, compared to the cloud, a

TABLE I

CLOUD-ROD RATIO $\left(\frac{\text{Cloud Height}}{\text{Rod Height}}\right)$	PROTECTIVE RATIO $\left(\frac{\text{Protective Radius}}{\text{Rod Height}}\right)$
4	2.0
6	2.7
8	3.3
10	3.9
20	5.0
40	5.3

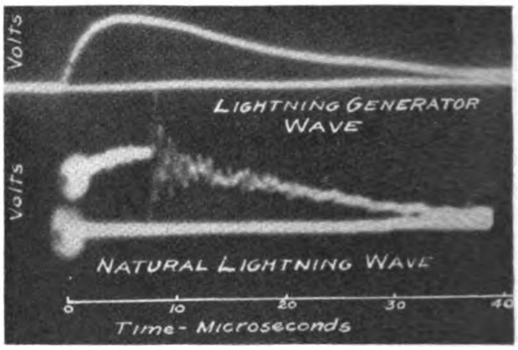

Fig. 39. Comparison of Natural Lightning Wave Measured on Transmission Lines with Cathode-ray Oscillograph with an Artificial Lightning Wave Measured in the Same Way

straight line drawn from the rod tip to the limit of the protective radius is sufficient. With a comparatively high rod, roughly over 10 per cent of the cloud height, the previously mentioned arc must be used. Thunderclouds are usually not lower than about 1000 feet.

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*Since this paper was written, over one hundred oscillograms of natural lightning waves on lines were obtained in the 1929 study, which were found to be in good agreement with the pioneer laboratory studies.

(5) Papers on Surge Voltage Investigations, by W. W. Lewis, Phillip Sporn, N. N. Smeloff, Hemstreet & Eaton, and E. W. Dillard, presented at Summer Convention of A.I.E.E., Denver, June 25-29, 1928.

LIGHTNING ON TRANSMISSION LINES

Because of progress in research during 1928, it seems desirable at this time to reëxamine transmission practice and see if changes are indicated.

Voltages on Transmission Lines

The rule given in former papers that the induced voltage depends upon the height of the conductor above ground is still indicated, thus:(1)

$$V = hg\,\alpha$$

where V is the voltage, h is the average height of conductor in feet or meters, depending on how g is expressed; g is the gradient (100,000 volts per foot or 330,000 volts per meter); and α is a reduction factor ($=$ or $<$ 1.0) depending upon the rate of discharge and size of the charged cloud over the line. This also applies in case of a direct stroke to the tower or nearby ground wire where the conductor is not actually hit. From the lightning standpoint, low towers with conductors in a horizontal plane are preferable. The maximum voltage wave that can travel on the line and reach the apparatus is determined by the line insulation. The fact that many induced lightning voltages are quite high means that a large number of cloud discharges must occur quite rapidly. The higher insulator sparkover voltages measured on lines indicate waves of effective duration from 5 to 20 microseconds, or a total duration of 10 to 40 microseconds. Lower voltage sparkovers result with longer durations. The indications are that an appreciable number of the high-voltage waves have fronts varying between zero and one microsecond. A large percentage of the wave fronts also vary between one and five microseconds.

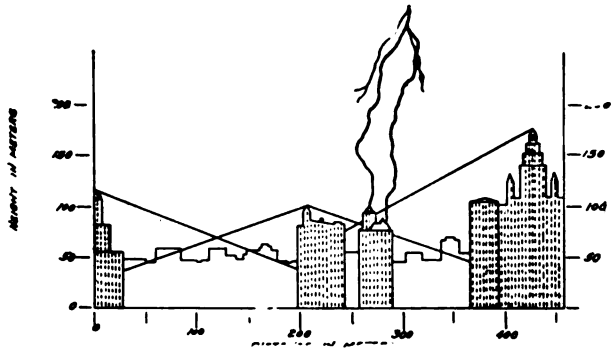

Fig. 40. Diagram of Lightning Striking Building in New York City. The protective cone is not violated. (*From photograph*)

Attenuation of a Traveling Wave

The distance that lightning can travel at high voltage on a transmission line is of extreme practical importance. This is borne out by the data in Table II, which are taken from measurements on lines. It is thus seen that 4000 kv. is reduced to half voltage or 2000 kv. in 1.5 miles (2.4 km.). This shows that a badly exposed section of a line could be highly overinsulated without much danger of subjecting the normally-insulated section to excessive voltages. It is only necessary to extend the highly insulated line several spans beyond the exposed section. Moderate reduction of insulation at a substation should not appreciably increase the outages. For instance, 2000 kv. is reduced 20 per cent in traveling less than 0.7 miles (1.1 km.) and to half in 2.1 miles (4.8 km.). Any outages within the reduced insulation section must be attributed to local storms and would not be due to line surges coming into the station from outside normally or abnormally insulated sections. Additional data on the attenuation factor from other lines is of course desirable.

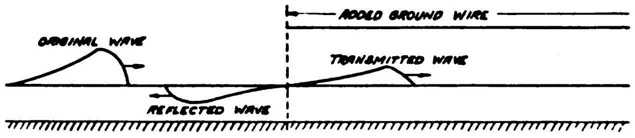

Fig. 41. Effect of Added Ground Wires in Reducing Voltages of Incoming Waves

TABLE II

Lightning Voltage (Kilovolts)	DISTANCE OF TRAVEL FOR REDUCTION TO HALF VOLTAGE		DISTANCE OF TRAVEL FOR REDUCTION TO 0.80 VOLTAGE	
	Miles	Kilometers	Miles	Kilometers
4000	1.5	2.4	0.4	0.6
3000	2.1	3.3	0.5	0.8
2000	3.0	4.8	0.7	1.1
1000	6.3	10.0	1.6	2.5

Value of a Ground Wire

Statistical data still decidedly indicate the great value of ground wires.(6) These data show that outages due to insulator arcovers are reduced from one-half to one-tenth or less after the installation of ground wires. Only on certain sections of lines, and then only rarely, have the ground wires had little effect. The reason seems to have been that, because of the peculiar location and design of the line, the arcovers were caused mostly by direct hits. Where the spans are long, where the ground wires are near the line conductors, or where the ground resistances are high, a direct stroke is likely to involve the line conductor. Special precautions should be taken in the design of towers, ground wires, or protecting rods to prevent direct strokes from side-flashing to conductors where the lines are in badly exposed places.

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(6) "1927 Lightning Experience on 132-kv. Lines," by Phillip Sporn, *Trans. A.I.E.E.*, 1929.

"Relation Between Transmission Line Insulation and Transformer Insulation," by W. W. Lewis; "Rationalization of Transmission System Insulation Strength," by Phillip Sporn. Both presented at A.I.E.E. Regional Meeting, New Haven, Conn., May 9-12, 1928.

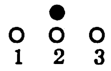
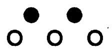
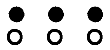
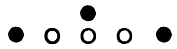
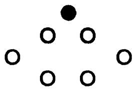
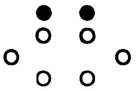
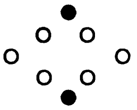
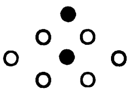
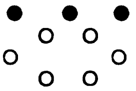
"Progress in Lightning Research in Field and Laboratory," by F. W. Peek, Jr., *Trans. A.I.E.E.*, 1929.

Table III shows various ground-wire arrangements around conductors and the corresponding reduction in lightning induced voltages (protective ratios) that they bring about.

The lightning corona loss, which greatly limits voltage, may be, on certain configurations, materially increased by ground wires. This action is shown on the grading shield in Fig. 20.

A reduction in the surge impedance by ground wires on sections of lines reduces the voltage of traveling waves coming in from other sections. This effect is shown qualitatively in Fig. 41. Quantitatively the reduction depends on the relative surge impedances which are subject to calculation. When ground wires are omitted an increase in voltage occurs. It is thus important to bring all ground wires up to the station metal bus structure. Extra ground wires extending about a half mile (one kilometer) from the station should be of value for station protection, since voltages caused by local storms would be reduced and waves from distant storms would be lowered by reduction in surge impedance. Whether the reduction in voltage obtained in this way is material or not depends on the relative distances between line and ground wire and between line and ground.

TABLE III
EFFECT OF GROUND WIRES ON LIGHTNING INDUCED VOLTAGES

Arrangement	Protective Ratio
	1 52 2 44 3 52
	1 40 2 34 3 40
	1 34 2 28 3 34
	1 28 2 25 3 28
	1 42 2 49 3 56
	1 33 2 38 3 44
	1 40 2 48 3 36
	1 32 2 34 3 40
	1 25 2 30 3 37

O Indicates conductor. ● Indicates ground wire.

$$\text{Protective ratio} = \frac{\text{Voltage with ground wire}}{\text{Voltage without ground wire}} \times 100$$

Average values for various relative conductor and ground-wire distances that have been used in practice.

"Lightning-proof Transmission Lines" and the Coördination of Transformer Insulation and Line Insulation

It has been pointed out that induced lightning voltages are independent of operating voltages and depend upon the height of the line; that ground wires reduce lightning voltages; and that the lightning flashover voltages of insulators and the breakdown voltage of apparatus is known. A study of the various factors shows that a line of moderate height, protected by ground wires and properly insulated, could usually be made lightning-proof against induced voltages at a reasonable cost. In making this comparison, the induced voltages were obtained by calculations using maximum values ($\alpha = 1.0$) from the formulas that have been given, making proper allowances for ground wires, and using insulator strengths in excess of these values as determined by Figs. 8 and 9.

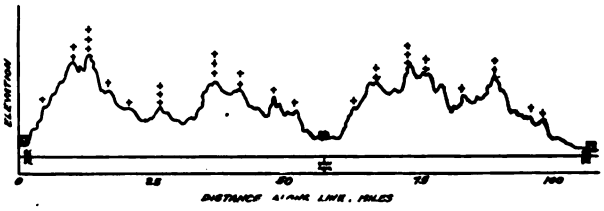


Fig. 42. Distribution of Flashovers Along a Transmission Line. + Indicates insulator flashover

As an example, assume that the average height of the horizontal conductors is 40 ft. (12.2 meters). Then $V = 100{,}000 \times 40 = 4{,}000{,}000$ volts or 4000 kv. With one or more ground wires, the voltage will be reduced to at least $\frac{4000}{2} = 2000$ kv. From Fig. 8, fifteen insulator units are found to have a lightning sparkover voltage with a margin well over this. With this insulation, flashovers should not result unless the conductors are hit directly. In order to make a line immune from direct strokes, the necessity of ground wires above the line is almost obvious. With ground wires, the stroke would usually take place to the wires and then along the wires to the tower, preventing insulation arcover. However, on sections where the line is badly exposed to direct strokes and where the spans are long or where the grounding resistance is high, special precaution should be taken in the design of the tower to prevent side flashes from ground wire to conductor. To assure immunity from direct strokes to the conductor, rods at the towers or alongside the line, or additional overhead ground wires might be used, and special precautions taken as to length of span, resistance to ground, distance from conductor to ground wire, etc. It is quite probable that discharge devices that permit the lightning to go to ground but not the power current to follow will be made available for use on insulator strings. The extent to which any line is to be made immune from lightning should be determined by economic as well as engineering considerations.

Since the limit of the voltage on any line is the lightning sparkover voltage of the insulator, it is very important, when designing a system, to so proportion the insulation that the lightning strength of the transformer is higher than the lightning breakdown voltage of the line insulators in the vicinity of the station.(4) (5) (6) The transformer should not be weaker than the adjacent insulation. Proper coördination should always be made (see Table IV). The insulators on the remainder of the line may be as strong as desired.

TABLE IV

Line Voltage	Standard A.I.E.E. Transformer Testing 60-cycle Voltage—Twice Line Voltage Plus One Kv. for One Minute	Number of Suspension Insulator Units (5¾-in. Spacing 10-in. Dia.)	60-cycle Flashover Voltage of Insulator Units
(Kv. eff.)	(Kv. eff.)		(Kv. eff.)
69.0	139.0	4	250
73.0	147.0	4	250
92.0	185.0	6	355
115.0	231.0	7	405
138.0	277.0	8	455
161.0	323.0	10	550
196.0	393.0	12	640
230.0	461.0	14	725

Note.—When a transformer is tested at 60 cycles according to the above A.I.E.E. rules, its lightning strength should be greater than the lightning strength of the insulators given in the third column. The lightning strength of the transformer bushing should be greater than the insulator flashover, but less than the transformer lightning breakdown. The fourth column gives the 60-cycle sparkover of the corresponding number of units in the third column. Where units of different spacings than those in the latter column are to be used, a sufficient number should be selected to give a flashover voltage corresponding to the value given in the fourth column. Suspension insulators of the same string length have approximately equal sparkover voltages. If the line insulation at the transformer is in excess of the tabulated value, the 60-cycle transformer test should be increased proportionately. The above applies only to suspension insulator strings, as pin-type insulators and bushings must be considered separately because of different impulse ratios.

The insulator string grading shield not only reduces the maximum stress on a line but increases the arc-over voltage and causes the arc to clear the string. The horn and similar arcing devices cannot cause the arc to clear without a serious reduction of the flash-over voltage.

The location of the line is very important as sections particularly exposed to lightning require extra insulators, ground wires, etc. A study of most lines shows that a large percentage of over-voltages occur on limited sections of the line (see Fig. 42). If these bad sections could be determined before the construction of the line, it is probable that the route could be changed to avoid them. The ideal line would thus be as low in height as practicable, be protected by one or more ground wires, and be well insulated with insulators protected by grading shields. Unavoidably exposed sections on the right-of-way should have extra insulation and additional ground-wire protection. The transformer insulation should be stronger than the bushing and the bushing stronger than the sparkover voltage of the line insulators in the immediate vicinity of the station. By immediate vicinity it is meant that the coördinated insulation should start within about 75 ft. (25 meters) of the apparatus and preferably extend out about one-half mile (0.8 km.). In lieu of this, a spark gap within 75 ft. of the apparatus and set with a lightning sparkover voltage about 10 per cent (see Figs. 7 and 8, Part I) lower than the normal line insulation could be used. Series inductance or choke coils may cause increased voltages and oscillations if not shunted by resistance of the proper values. As has been pointed out, such coördination of the insulation should not increase outages, because a very small percentage of the line is involved. As a precaution, extra ground wires may be added on the coördinated section to provide against local storms. With extra ground wires, the lightning voltages can be reduced in proportion to the reduced insulator strength. This coördination of insulation has been in effect now for several years on one system with results as expected. It is not intended to take the place of the lightning arrester, as good lightning arresters are recommended as in the past. A "coördinating" gap, however, offers a good check on the condition of the arrester and grounds.

(Concluded)

The Electrification of the Mexican Railway

PART IV

By J. B. COX
Transportation Engineering Department, General Electric Company

IN the concluding section of this article it should be explained that while the detailed operating costs, taken from the comparison between steam and electric performance, cover in each instance a period of only two months, the records for a considerably longer period of steam operation were carefully examined. The months of September and October, 1921, were selected by the management of the Railway Company as being most representative of the traffic conditions and operating expenses which it was expected would be likely to continue in the future if the steam locomotives were retained.

The country was just recovering from the depression caused by the revolutions that had existed for several years, and the road had been back in the hands of the owners only a little more than a year, so that there were really only four months' records that could be considered fairly representative of expected conditions. These months were July, August, September, and October, 1921. The operating costs that would be appreciably affected by electrification for these four months were recorded in the report in Table XXXI.

It was after a general study of these four months that September and October were selected for more detailed analysis for the purpose of preparing an estimate of results to be expected from electrification. The dispatcher's daily train sheets for the two months were gone over carefully and a complete record of each train movement prepared; from these data averages of running time, delayed time, elapsed time, and train weights were determined. A diagram was made up for checking comparative theoretical curves showing the probable elapsed time for steam and electric locomotives over the same profile.

TABLE XXXI

OPERATING COSTS OF STEAM OPERATION FOR FOUR MONTHS, 1921

MEXICAN RAILWAY COMPANY

	July	August	September	October	Total	Yearly Rate
Enginemen	$7,548	$9,625	$8,476	$9,507	$35,156	$105,468
Trainmen	5,745	6,720	6,707	7,508	26,680	80,040
Fuel	19,369	21,570	17,551	19,413	77,903	233,709
Repairs	24,887	27,523	28,832	30,426	111,668	335,004
Enginehouse	2,028	1,427	2,185	1,305	6,945	20,835
Lubricants	1,095	1,287	1,412	1,364	5,158	15,474
Total	$60,672	$68,152	$65,163	$69,523	$263,510	$790,530
COST PER 1000 TON-MILES						
Enginemen	....	....	$1.7301	$1.8818	....	....
Trainmen	....	....	1.3690	1.4861	....	....
Fuel	....	....	3.5826	3.8426	....	....
Repairs	....	....	5.8851	6.0226	....	....
Enginehouse	....	....	0.4460	0.2583	....	....
Lubricants	....	....	0.2882	0.2698	....	....
Total	....	....	$13.3012	$13.7614	....	....
1000 Ton-miles	....	....	4,899	5,052	....	....
Locomotive-miles	58,844	61,513	57,541	61,822	239,721	719,163

COST PER LOCOMOTIVE-MILE (CENTS)

	July	August	September	October	Average
Enginemen	12.828	15.648	14.731	15.379	14.665
Trainmen	9.764	10.925	11.656	12.145	11.130
Power	32.918	35.069	30.502	31.403	32.498
Repairs	42.296	44.746	50.108	49.217	46.583
Enginehouse	3.447	22.320	3.797	2.111	2.897
Lubricants	1.861	2.092	2.454	2.206	2.152
Total	103.114	110.800	113.248	112.461	109.925

An examination of the four months' operating records indicated that the two months suggested by the management would be fairly representative.

In the case of electrical operation the months of March and April, 1928, were also selected for the comparison by the management of the railway because the traffic during those months was the heaviest in the history of the road, and it was considered that these two months were most desirable for comparing with the two months of steam operation that had been used in the report.

In this instance also the records for January, February, March, and April were gone over carefully to ascertain if there were any variations requiring consideration. Various other monthly records of electrical operation were also compared; but only the months of March and April were analyzed in detail, exactly as had been done in the report for September and October steam operation.

Table XXXII shows the operating costs of electrical service for the four months, and Table XXXIII the electrical operating cost for 39 months from October 1, 1925, to April 30, 1928, inclusive, covering practically the entire period during which the electrification has been in complete operation. Eight months of the year 1928 include the operation of the entire electrification from Esperanza to Paso del Macho.

A careful analysis of these figures will indicate that the total cost per ton-mile decreases as the total ton-miles increase, as would be expected. The power contract calls for a minimum charge which usually covers the demand (or ready-to-serve item of the power bill), so that in case of extremely light traffic for any month, the cost of this item remains fixed, making the cost of power on a ton-mile basis much higher. On the other hand, a considerable increase in traffic can usually be handled within the specified peak limit by the careful dispatching of trains, which increases the

TABLE XXXII

OPERATING COSTS ORIZABA-ESPERANZA DISTRICT FOR FOUR MONTHS' ELECTRICAL OPERATION, 1928

MEXICAN RAILWAY COMPANY

	January	February	March	April	Total	Yearly Rate
Enginemen	$4,776	$5,517	$7,839	$6,726	$24,858	$74,574
Trainmen	2,850	3,619	6,010	4,711	17,190	51,570
Power	13,740	14,054	14,560	16,580	58,934	176,802
Repairs	2,888	2,534	2,251	3,717	11,390	34,170
Enginehouse	777	756	965	980	3,478	10,434
Lubricants	22	51	47	45	165	495
Substation	869	944	1,052	1,102	3,967	11,901
Distribution	439	269	444	412	1,564	4,686
Total	$26,361	$27,744	$33,168	$34,273	$121,546	$364,632

Cost Per 1000 Ton-miles

	January	February	March	April	Average	Yearly Rate
Enginemen	$0.9435	$0.9268	$0.9282	$0.9065	$0.9248	......
Trainmen	0.5631	0.6079	0.7116	0.6349	0.6395	......
Power	2.7143	2.3608	1.7241	2.2345	2.1925	......
Repairs	0.5705	0.4256	0.2665	0.5009	0.4237	......
Enginehouse	0.1535	0.1270	0.1143	0.1321	0.1294	......
Lubricants	0.0043	0.0086	0.0056	0.0061	0.0061	......
Substations	0.1717	0.1586	0.1246	0.1485	0.1476	......
Distribution	0.0867	0.0452	0.0526	0.0555	0.0582	......
Total	$5.2076	$4.6605	$3.9275	$4.6190	$4.5218	......
1000 Ton-miles	5,062	5,953	8,445	7,420	26,880	80,640
Engine miles	20,780	23,490	32,119	29,256	105,645	316,935

Cost Per Locomotive-mile (Cents)

	January	February	March	April	Average
Enginemen	22.984	23.487	24.406	22.990	23.529
Trainmen	13.715	15.407	18.712	16.103	16.270
Power	66.121	59.828	45.331	56.668	55.782
Repairs	13.899	10.789	7.008	12.706	10.780
Enginehouse	3.739	3.219	3.004	3.349	3.293
Lubricants	0.106	0.217	0.146	0.154	0.156
Substation	4.182	4.018	3.275	3.767	3.755
Distribution	2.113	1.145	1.382	1.408	1.480
Total	126.857	118.120	103.265	117.145	115.045

load-factor, thus limiting the cost for extra power to one-tenth of a cent per kw-hr., a rate additional to the charge per peak demand.

The full four months of steam operation, as given in Table XXXI, compared with the four months of electrical operation, as in Table XXXII, gives a total saving of $141,964 for the four months in favor of electrical operation, or 54 per cent. This is at the rate of $425,892 per year, whereas the two-month comparison shows a saving of 50 per cent, or at the rate of $402,612, no adjustments being made in either case for increased tonnage or wages.

Unfortunately the record of the ton-miles for July and August, 1927, were not recorded in the report, rendering a proper adjustment for this term impracticable.

For the purpose of checking the savings shown herein, similar comparisons of the results shown on other electrified roads were prepared. Table XXXIV gives the yearly rate of operating costs for the Butte, Anaconda & Pacific Railway; two divisions of the Chicago, Milwaukee, St. Paul & Pacific Railroad; and the Paulista Railway of Brazil, together with that of the Mexican Railway, and a combined result showing the average result of all the five electrifications.

It will be noted that in every instance a substantial saving is shown in each item listed; the average saving varying per item from 41 to 70 per cent, with a total average saving of 52.7 per cent in favor of electrical operation.

These records of operating expenses, which in each case have been supplied and approved by the operators, should be an incentive alike to the electrical industry and the railroad operating fraternity for a mutual interest in the subject of railway electrification. A few hours' study of the operating costs, and a general inspection of the line and equipment will usually indicate whether or not a detailed study and estimate are worth while.

The figures for comparative costs of operation as well as for the cost of construction were taken from the official records of the Mexican Railway Co., Ltd., and were approved by them. The figures relating to the original estimate were taken from the original report. The comparison of operating costs are from a report asked for by the chairman of the board of the Mexican Railway Co., Ltd., who after inspecting the completed electrification in April, 1928, called the author of the report (a copy of which he held in his hand) and, pointing to the paragraph which predicted the savings that might be expected from electrification, said: "You have apparently done reasonably well in meeting the promises in the report thus far, and we have no doubt that the electrification does even more than promised so far as handling the traffic is concerned, but my directors wish to know if the savings accomplished are sufficient to justify the ex-

TABLE XXXIII

OPERATING COSTS OF ELECTRIFIED DISTRICT

MEXICAN RAILWAY COMPANY

	1925 Oct., Nov., Dec.	1926 Year	1927 Year	1928 Year	Total 39 Months	Average Yearly Rate
Enginemen	$9,221	$43,012	$54,992	$80,835	$188,060	$57,865
Trainmen	4,789	25,970	34,193	53,033	117,985	36,303
Power	40,531	163,668	164,840	195,680	564,719	173,760
Repairs	4,493	21,768	36,868	42,514	105,643	32,505
Enginehouse	5,644	11,562	9,998	16,810	44,014	13,543
Lubricants	747	2,173	668	733	4,321	1,329
Substations	4,966	15,130	12,831	18,309	51,236	15,765
Distribution	2,587	9,308	4,510	5,775	22,180	6,825
Total	$72,978	$292,591	$318,900	$413,689	$1,098,158	$337,895
Per 1000 Ton-miles						
Enginemen	$0.94925	$0.98075	$0.95431	$0.81630	....	$0.89458
Trainmen	0.49300	0.59217	0.59337	0.53555	....	0.56124
Power	4.17243	3.73194	2.86056	1.97605	....	2.68132
Repairs	0.46253	0.49637	0.63979	0.42932	....	0.50254
Enginehouse	0.58102	0.26363	0.17350	0.16975	....	0.20932
Lubricants	0.07690	0.04955	0.01159	0.00780	....	0.02055
Substations	0.51122	0.34500	0.22266	0.18489	....	0.24373
Distribution	0.26632	0.21224	0.07826	0.05832	....	0.10551
Total	$7.51267	$6.67165	$5.53405	$4.17758	....	$5.22380
1000 Ton-miles	9,714	43,856	57,625	99,026	210,221	64,683
Engine-miles	37,898	199,424	231,895	355,093	824,310	253,633
Cost Repairs per Engine-mile (Cents)	11.855	10.915	15.898	11.972	....	12.816
Per 100 Tons on Drivers	7.903	7.277	10.599	7.982	....	8.544

penditure made. Will you obtain all the operating data necessary for March and April this year for a comparison with September and October, 1921, and make us a statement showing whether or not the savings are as favorable as predicted?"

The operating costs for the Orizaba-Esperanza district have been kept during electrical operation precisely as they were during steam operation, so that the comparison between steam and electric operation herein is perhaps more direct and more free of adjustments than any other such comparison on record. The railways of Mexico are generally operated with standard American equipment and by almost identical methods, so that the operating costs are for all practical purposes as comparable as they would be on any American road. The cost of supplies are slightly higher and wages are about proportional for the amount and character of the work done.

The steam locomotives formerly used were well adapted to the service at the time they were purchased, and the later ones which had almost exactly the same weight on drivers as their electric successors were about as efficient for this mountain service as any modern locomotive not equipped with superheat and water-heating equipment. It should be mentioned here that about 30 per cent of the locomotive-miles made on the Orizaba-Esperanza district during September and October, 1921, were made by the ten new Consoli-

TABLE XXXIV

COMPARATIVE OPERATING COSTS AND SAVINGS OF STEAM ROAD ELECTRIFICATIONS

BUTTE, ANACONDA & PACIFIC RAILWAY

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$112,817	$71,225	$41,592	37
Trainmen.....	159,442	116,486	42,956	27
Fuel or power.	340,455	164,509	175,946	52
Repairs.......	134,771	92,278	42,493	31
Enginehouse ..	32,301	18,639	13,662	42
Lubricants....	10,531	4,942	5,589	53
Other supplies	6,289	4,552	1,737	28
Water........	5,350	1,194	4,156	..
Substations...	......	16,400	......	..
Trolley & trans.	......	17,816	......	..
Total.....	$801,956	$508,041	$293,915	36

MEXICAN RAILWAY

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$185,946	$87,390	$98,556	53
Trainmen.....	130,332	64,326	66,006	50
Fuel or power.	300,834	186,840	113,994	38
Repairs.......	408,354	35,814	372,540	91
Enginehouse...	23,388	11,670	11,718	50
Lubricants....	19,146	552	18,594	97
Other supplies	......	......	......	..
Water........	......	......	......	..
Substations...	......	12,924	......	..
Trolley & trans.	......	5,136	......	..
Total.....	$1,068,000	$404,652	$663,348	62

CHICAGO, MILWAUKEE, ST. PAUL & PACIFIC RAILROAD

HARLOWTON-AVERY DIVISION

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$561,406	$327,230	$234,176	42
Trainmen.....	473,223	319,056	154,167	33
Fuel or power.	1,200,017	763,720	436,297	36
Repairs.......	943,654	338,326	605,328	64
Enginehouse..	221,044	87,028	134,016	60
Lubricants....	18,671	15,185	3,486	19
Other supplies	25,207	7,604	17,603	69
Water........	26,196	......	26,196	..
Substations...	......	108,881	......	..
Trolley & trans.	......	64,812	......	..
Total.....	$3,469,418	$2,031,842	$1,437,576	41

OTHELLO-TACOMA DIVISION

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$328,626	$136,715	$191,911	58
Trainmen.....	365,542	164,919	200,623	55
Fuel or power.	705,016	322,348	382,668	54
Repairs.......	479,782	141,910	337,872	70
Enginehouse...	82,056	31,867	50,189	61
Lubricants....	7,870	7,080	790	10
Other supplies	10,515	5,528	4,987	47
Water........	16,860	......	16,860	..
Substations....	......	63,686	......	..
Trolley & trans.	......	37,047	......	..
Total.....	$1,996,267	$911,100	$1,085,167	54

PAULISTA RAILWAY

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$226,488	$63,232	$163,256	72
Trainmen.....	......	......	......	..
Fuel or power.	920,063	132,950	787,113	85
Repairs.......	141,876	24,032	117,844	83
Enginehouse...	174,518	34,867	139,651	80
Lubricants....	26,714	5,425	21,289	79
Other supplies.	75,188	26,669	48,519	65
Water........	......	......	......	..
Substations...	......	29,993	......	..
Trolley & trans.	......	29,261	......	..
Total.....	$1,564,847	$346,429	$1,218,418	78

COMBINED RESULT

	Steam	Electric	Reduction	
			Amount	Per Cent of Steam
Enginemen....	$1,415,283	$685,792	$729,491	51.5
Trainmen.....	1,128,539	664,787	463,752	41
Fuel or power.	3,466,385	1,570,367	1,896,018	55
Repairs.......	2,108,437	632,360	1,476,077	70
Enginehouse...	533,307	184,071	349,236	65.5
Lubricants....	82,932	33,184	49,748	60
Other supplies	117,199	44,353	72,846	62
Water........	48,406	1,194	47,212	97.5
Substations...	......	231,884	......	..
Trolley & trans.	......	154,072	......	..
Total.....	$8,900,488	$4,202,064	$4,698,424	52.7

dation engines herein listed. This fact, however, would not materially affect the cost of locomotive repairs for those months, since the shop was behind with such work at the time and proceeded at the regular rate throughout the period.

The original report did not enter into the subject of new steam locomotives as the introduction of the ten new Consolidated locomotives into the service had made it evident that these would not sufficiently increase the capacity of the line or accomplish the desired saving. A report was then requested, showing what might be expected from electrification. At the time (October, 1921) the improvements which have recently been made in the economy of steam locomotives had not been brought to their present state of perfection. Modern locomotives had been considered by the management at the time the ten new Consolidated locomotives were purchased, but the electrification looked so favorable and offered so many additional advantages that no detailed comparison was required.

In general, where electrification has been compared with most modern steam operation, the cost of locomotives very nearly balance, thus reducing the gross cost of electrification from 40 to 50 per cent.

However, modern steam equipment would show a considerable saving over the old steam locomotives, which amount would of course be deductable from the saving that electrification would accomplish over the old steam locomotives. For instance, in the case of the Mexican Railway the savings expected from electrification over the old steam locomotives per year was estimated at $520,000. Had the mountain district been equipped with the largest steam locomotives with all the most modern improvements, it would have been possible to have handled the existing traffic at a considerable reduction in operating expenses, ordinarily about half the saving estimated for the electrification, which would have given about the same rate of return on the required investment for the new steam locomotives as had been predicted for the electrification. But the management realized that even with the adoption of the most modern and best adapted steam locomotives, the capacity of the single-track line between Orizaba and Esperanza might soon be reached and that double-tracking would have to be considered. The cost of a second track on a steep mountain side with seven tunnels would be a very expensive undertaking, estimated for the thirty miles involved at approximately $5,000,000, or about double the cost of electrification. Double-tracking would have increased the capacity of the line beyond the expected requirements of the near future, but would not have accomplished a saving in operating expenses which, alone, would have been at all satisfactory for the expense involved; whereas the electrification, costing much less and meeting any anticipated requirements, promised sufficient saving in operating expenses to make the investment attractive, even had it promised no additional advantages, such as increased capacity and improved conditions generally. In many such instances it is questionable if an economic mistake has not been made in this very matter of double-tracking congested districts and purchasing more powerful steam locomotives, which though increasing the capacity of the line and showing marked savings in operating expenses, cost more than electrification would have cost, and accomplish much less saving. Such mistakes have been largely due to the failure of the electrical manufacturer and the power producer to familiarize themselves with practical steam railway operating problems sufficiently to be able to present the full advantages of electrification to the aggressive steam-operation official. The power producer has been inclined to stick too closely to the standard power contract when discussing rates for railway electrification, he being afraid of the effect of possible peak loads on his plant, has been inclined to insert protective clauses in the contract which have been equally alarming to the railway manager as to the effect on his pocketbook. Happily the general tendency for the consolidation of the many smaller power companies into larger companies and the interconnection of these larger corporations physically as well as financially, is rapidly leading to material economies and greater reliability which will enable the power producer to supply any necessary peak demand without greatly increasing his investment, and thus be able to offer a dependable service at an attractive rate.

The object of presenting the results of the electrification herein described is to give true information to all of those who are interested. There are many sections of railway line that might be electrified with equally satisfactory results, but a careful study of the actual conditions is necessary to definitely determine the extent of the advantages to be expected.

It will be of interest to note the following quotations from comments made in communications from Mr. W. T. Ingram, Resident Engineer and Assistant General Manager of the Mexican Railway, and Mr. C. I. Luque, Superintendent of Transportation of the line, to both of whom the author is greatly indebted for their whole-hearted coöperation, not alone in securing the data for this article, but for their able support throughout the original study, the carrying out of the construction, and the initial operating period.

From Mr. Ingram:

"Referring to yours of the 19th, please note that our chief accountant has orders to put on a man to make up the statements you require for the Orizaba-Cordoba and Cordoba-Paso del Macho electrifications, dividing the total costs into material, labor, freight and duties. We will also prepare the statement for you based on the information furnished by the locomotive superintendent. This report shows very steadily that the cost per ton-kilometer between Orizaba and Esperanza was about 1½ centavos for steam, and ¾ centavos for electric operation.

"As regards the effect electrification has had on track maintenance, it would be impossible to say what this is in dollars and cents, but there is no doubt that the life of the line has been increased and the same applies to labor. No reduction has been made in the track force, but we have very much better track and this has meant freedom from accidents, less wear and tear on equipment and an improvement of train schedule."

From Mr. Luque:

"The electrification of the Mountain Section has meant to the Transportation Department the reduction of the operating problems peculiar to heavy-grade railroading to those of level roads.

"During the four years that electricity has been used as motive power we have been able to reduce not only train and engine crews to nearly one-half of what we had during steam operation but also telegraphers and other employees.

"There is an absolute dependability on the running time of trains handled with electric locomotives, which makes the work of the train dispatcher a matter of certainty in figuring out meeting and passing points, which with steam operation was only a guess.

"From the moment the train is ordered to round house and yard forces, time is calculated exactly—no allowances for getting up steam, caulking flues, cleaning fires, watering, etc., to which a steam engine that has been on the road and must be 'returned to the road as soon as ready' is wasted.

"Meeting points are made with precision unknown before, and as to safety and simplicity of operation, it is unsurpassable.

"On a railroad like ours, where traffic conditions have not been the best, it is quite a serious matter to acquire modern cars and coaches at the rate it is done elsewhere per annum, yet, perforce, we have to put up with weak or rather light old equipment which is a drawback in the operation of long tonnage trains. In spite of this handicap and considering our very heavy 4½ per cent grades, we have operated with 50 per cent of such 'soft shell' equipment without yet having destroyed or burst a car; very few draw-heads pulled off, chargeable really to 'age' defects and not to rough handling, which is a hard matter to control with a 150-ton locomotive ahead of and another behind 15 to 20 cars on a train, were it not for the ease and flexibility of the multi-motored electric engine.

"The regenerative braking is another very important feature on our electric locomotives—to bring down our grades trains of 30 to 40 cars without using air or hand brakes is something which when first told to our men was not believed. Even today after so many years one often wonders, as these long trains marshal down the steep slopes of the mountain, at this marvelous performance at an even speed, without jerking, shoving, and pulling like they used to do when controlled by compressed-air brakes. The expense of changing brake shoes, cooling off wheels, flattening of same, etc., has disappeared in its entirety.

"Were it not for the electrification of the mountain, we would have to operate the second division as a division instead of as so many districts as we do now. Divisional officers and offices are now a thing of the past, and our line is operated for all practical purposes as one division instead of two. What used to be a matter of discomfort and even concern to our passengers going through tunnels on account of smoke has also disappeared."

(*Concluded*)

PREPARE FOR THE NEW YEAR—

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THIS special number of the GENERAL ELECTRIC REVIEW will contain the annual summary of "Developments in the Electrical Industry During 1929," by John Liston, of the General Electric Company.

Another feature of the January issue will be the article "Progress in Radio Receiving During 1929," by Dr. Alfred N. Goldsmith, of the Radio Corporation of America.

Although you may not now be a subscriber, you will want this annual resumé of the electrical industry on hand to consult throughout the coming year.

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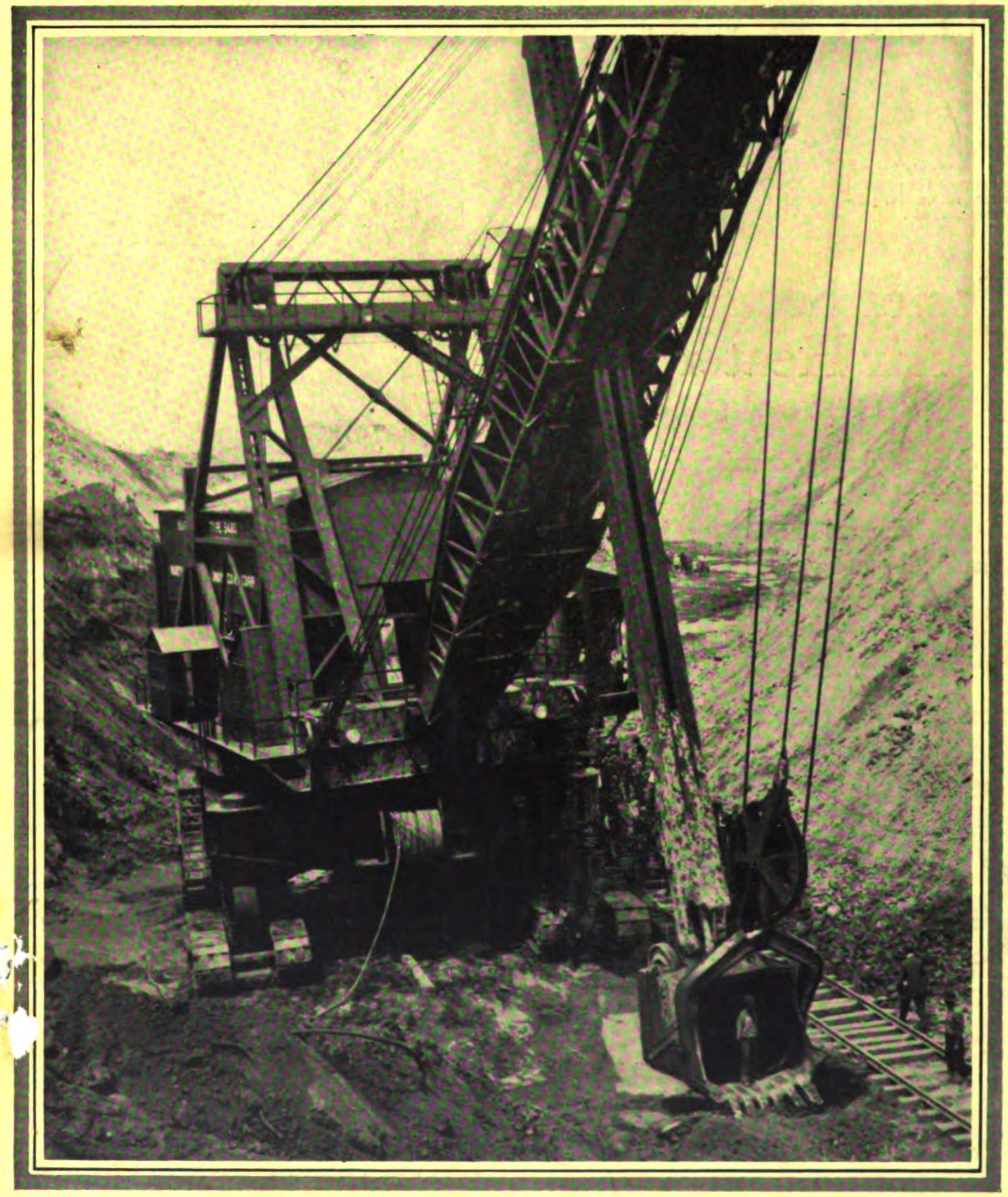
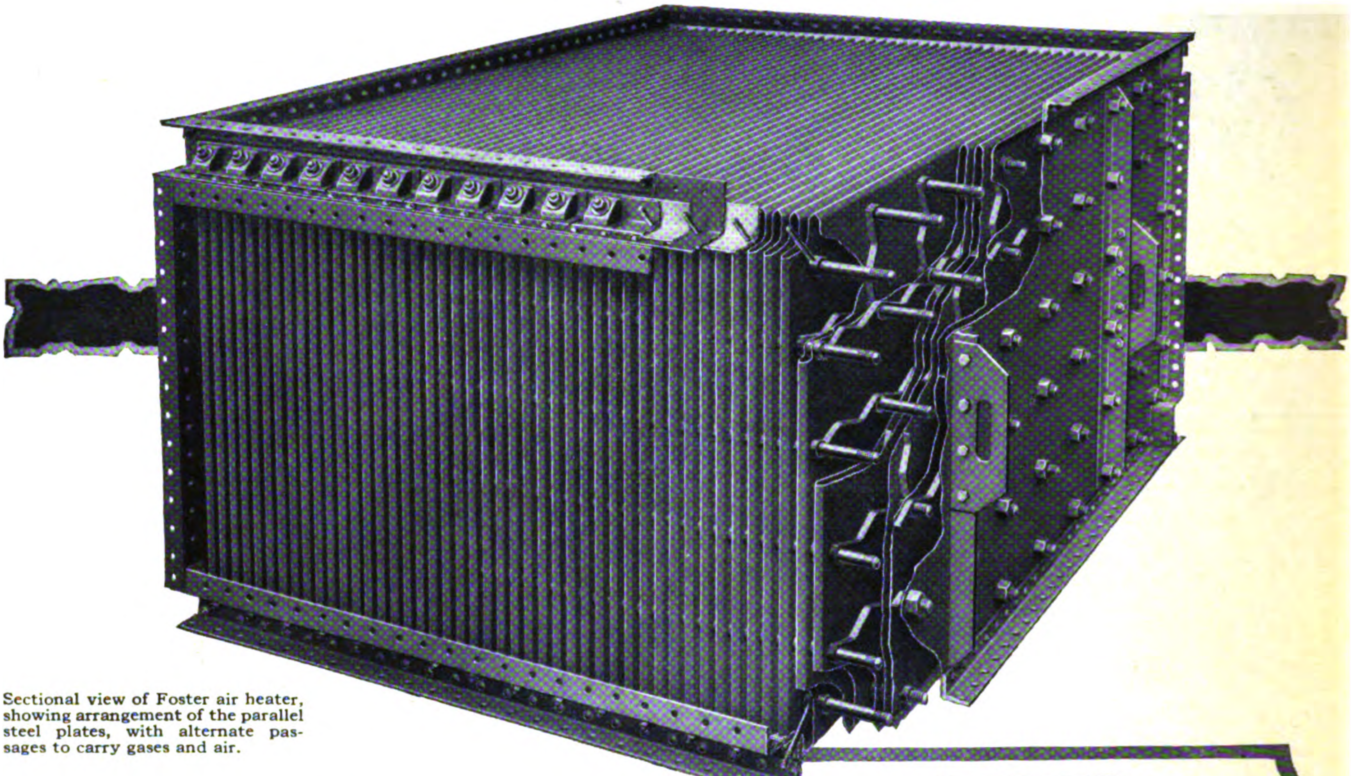


A GIANT OF THE ELECTRICAL AGE

Mammoth shovel for unearthing the resources of prehistoric times to make them available for the industrial processes of today. (*See p. 27*)

In This Issue: *A Review of the Progress Made in the Electrical Industry, and the Advancement in Radio Reception During 1928*



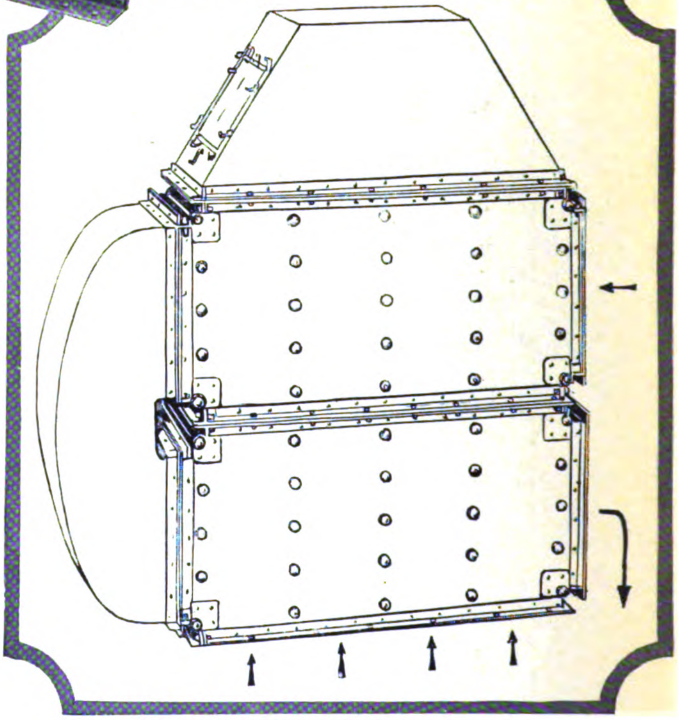
Sectional view of Foster air heater, showing arrangement of the parallel steel plates, with alternate passages to carry gases and air.

Foster Sectional Air Heater

(Haber Patents)

The Foster air heater consists of a number of interchangeable sections, completely assembled at the shops. Each section is made up of parallel steel plates, so arranged that alternate passages carry gas and air. Gases pass vertically and the air horizontally past the plates, flowing counter-current to each other.

The complete Foster air heater may consist of any number of interchangeable sections, depending upon station conditions and requirements to be fulfilled. The sections are arranged for series of parallel flow of gases and air. Installations now in operation are showing a five to ten per cent saving in fuel and a ten to twenty per cent increase in boiler capacity.



Diagrammatic sketch of two sections of a Foster air heater arranged one above the other and bolted together. Arrows indicate direction of flow of the gases and air. Gases pass upward through the sections. Air is drawn horizontally through the upper sections then down through the connecting duct and horizontally through the lower section, discharging downward to the furnace at the lower right connection.

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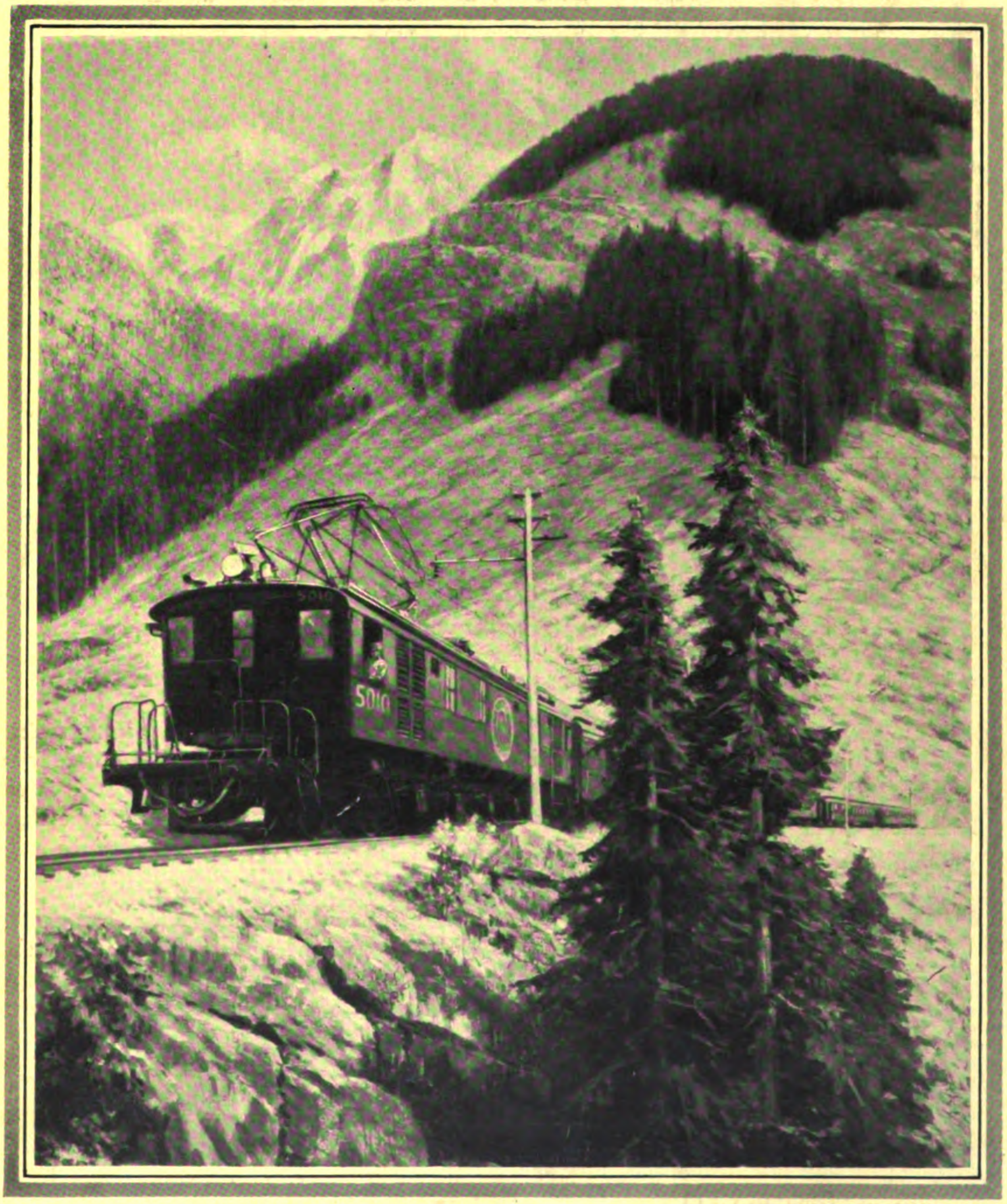
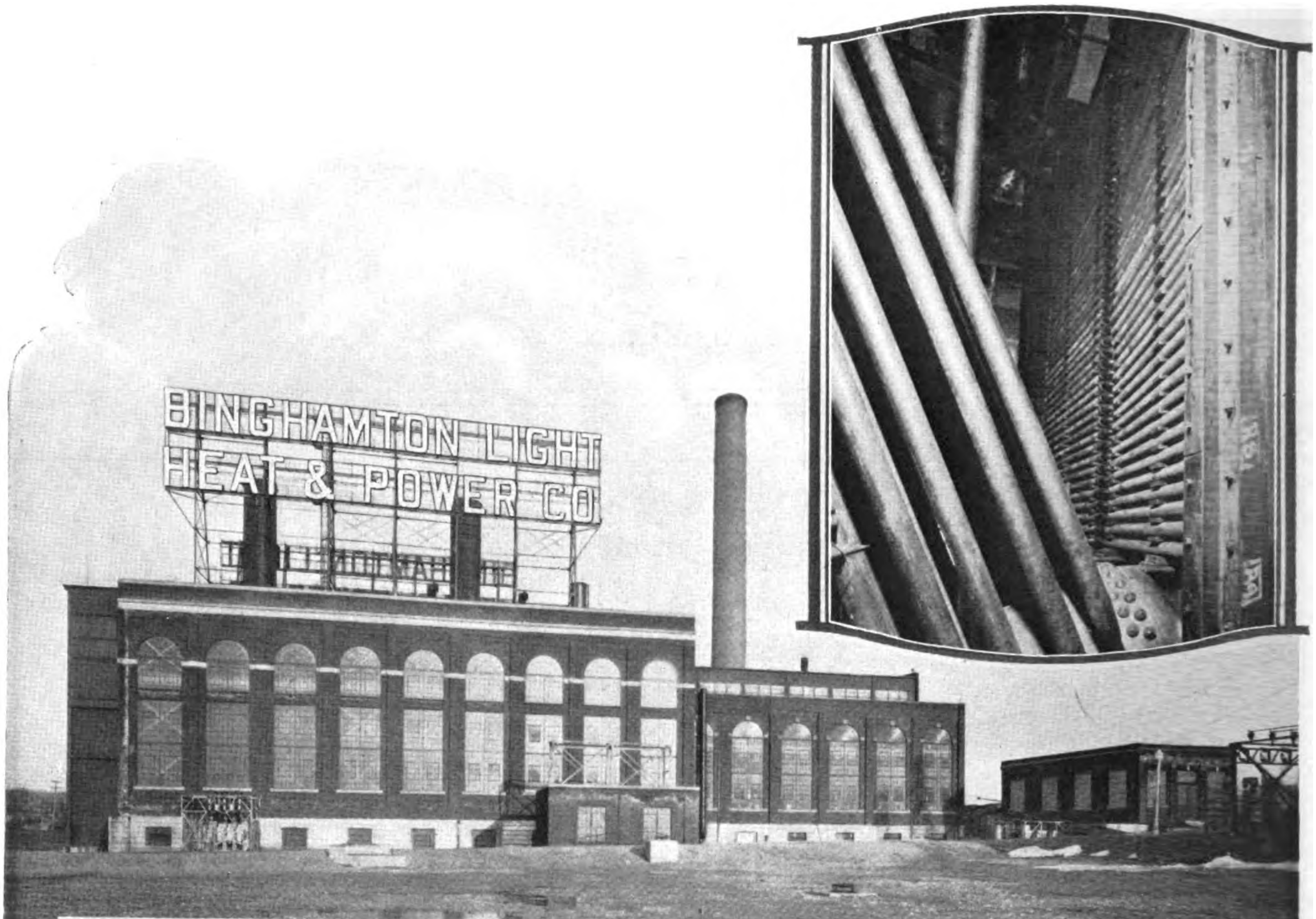
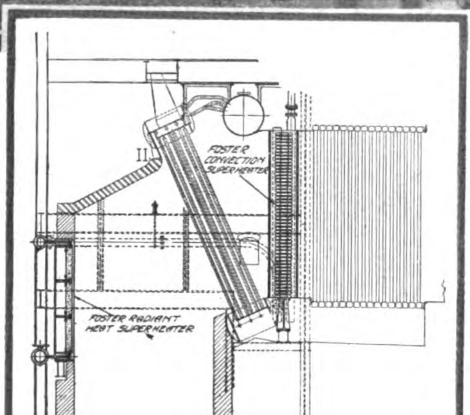


BETWEEN SKYKOMISH AND WENATCHEE VIA THE NEW CASCADE TUNNEL

Freight and passenger trains, drawn by electric locomotives which are among the largest of their kind, are now in regular service in crossing the Cascades through the recently-extended electrification of the Great Northern Railway

In This Issue: *Engineering Development and Research*
Volt-ampere Measurement
Future Trend in Ship Electrification
New Theory of Transformer Circuits
New Equivalent Circuits for Transformers
Design Features of the Holland Station




FOSTER CONVECTION SUPERHEATER
II
FOSTER RADIANT HEAT SUPERHEATER

Arrangement of Foster combination superheater for installation in the Edge Moor single-pass boiler at Binghamton. (Above, to right) Foster convection type superheater as installed in the single-pass boiler.

Binghamton Light, Heat & Power Co.
Binghamton, N. Y.

A rather unusual arrangement of Foster combination convection and radiant heat superheater is used in the Edge Moor single-pass boiler at the Binghamton Light, Heat & Power Company.

The installation consists of an unusually large vertical convection superheater area made up of two banks of standard Foster extended surface superheater elements. These are connected in series with a Foster radiant superheater, the elements of which are placed vertically in the front wall of the furnace and above the pulverized coal burners.

Foster combination superheaters have the characteristics of giving an even superheat over a wide range of ratings. At Binghamton, **the final temperature ranges only 20 degrees F. for outputs between 50,000 and 150,000 lbs. of steam per hour. The boilers operate at 450 lbs. per sq. inch pressure.**

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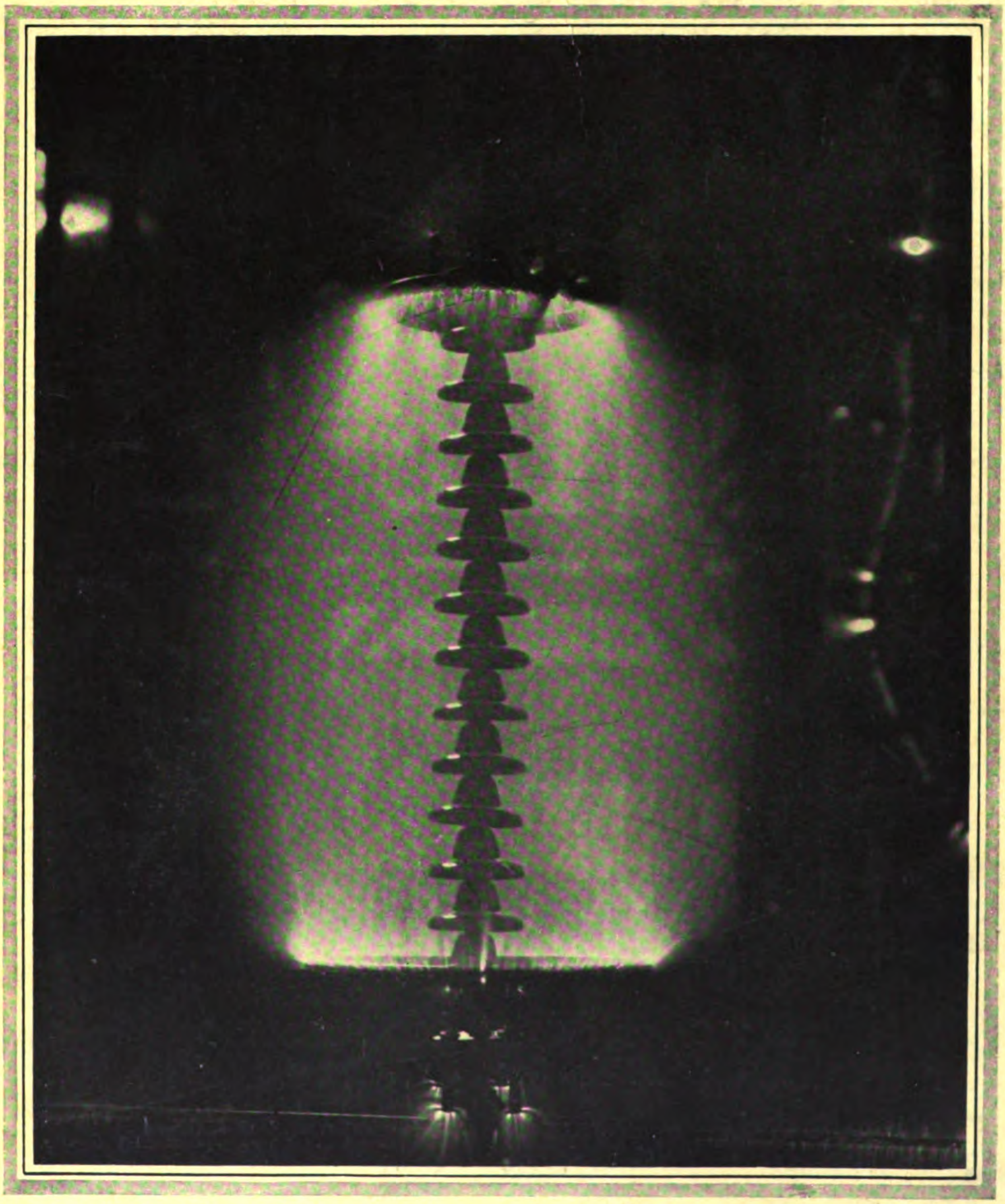
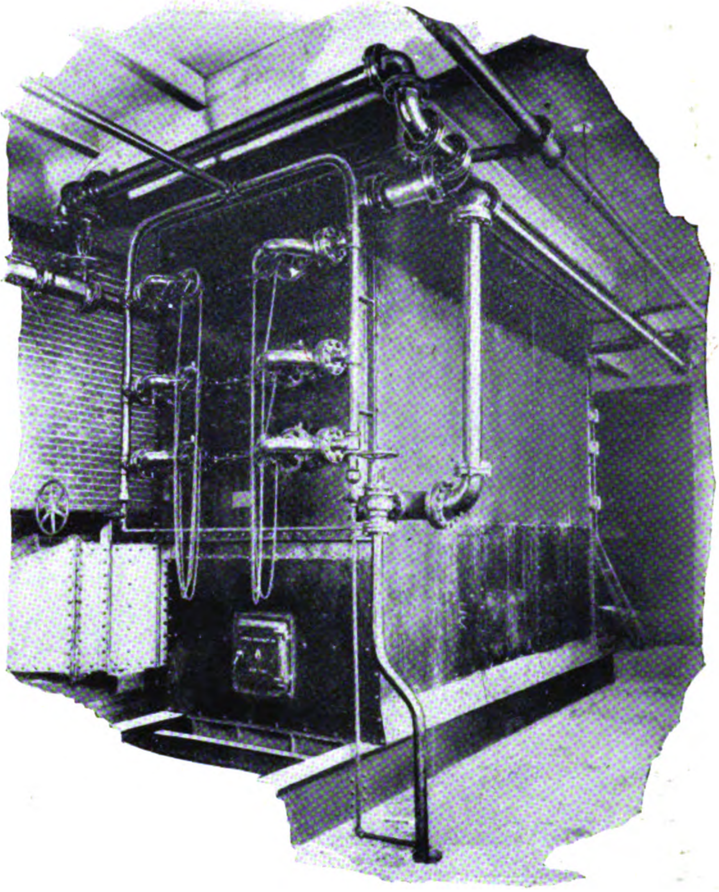


A STRING OF INSULATORS IN A "BARREL" OF CORONA

Correctly designed and applied grading shields increase the overall dielectric strength of a string of insulators. The mechanical strength of individual insulators is increased by a proper glazing, as explained by D. H. Rowland in this issue. The above photograph was taken in the High-voltage Laboratory at Pittsfield, where F. W. Peek, Jr., recently succeeded in generating the record man-made potential of 5,000,000 volts, which achievement he will describe in a later issue of this magazine

In This Issue: *Oil-immersed Reactors* *Flux Plotting* *Coöperation and Corporations*
Low-voltage A-c. Networks *Equipment in North Station* *Insulator Glaze*
Industrial Electric Heat *Welding Specifications* *A-c. Operation of Tube Filaments*



Foster Economizers

Foster economizers, placed close to the last pass of the boiler, absorb heat from the gases on the way to the stack. The heat recovered is transferred to the boiler feed water.

The flow of gases and water in the economizer is counter-current. Foster economizer elements provide the largest area of heat-absorbing surface per unit space occupied.

The design of Foster economizers permits their installation in a limited space—often that ordinarily occupied by the flue. These economizers may be applied to existing as well as to new boiler plants.

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VOL. 32, No. 4 APRIL, 1929

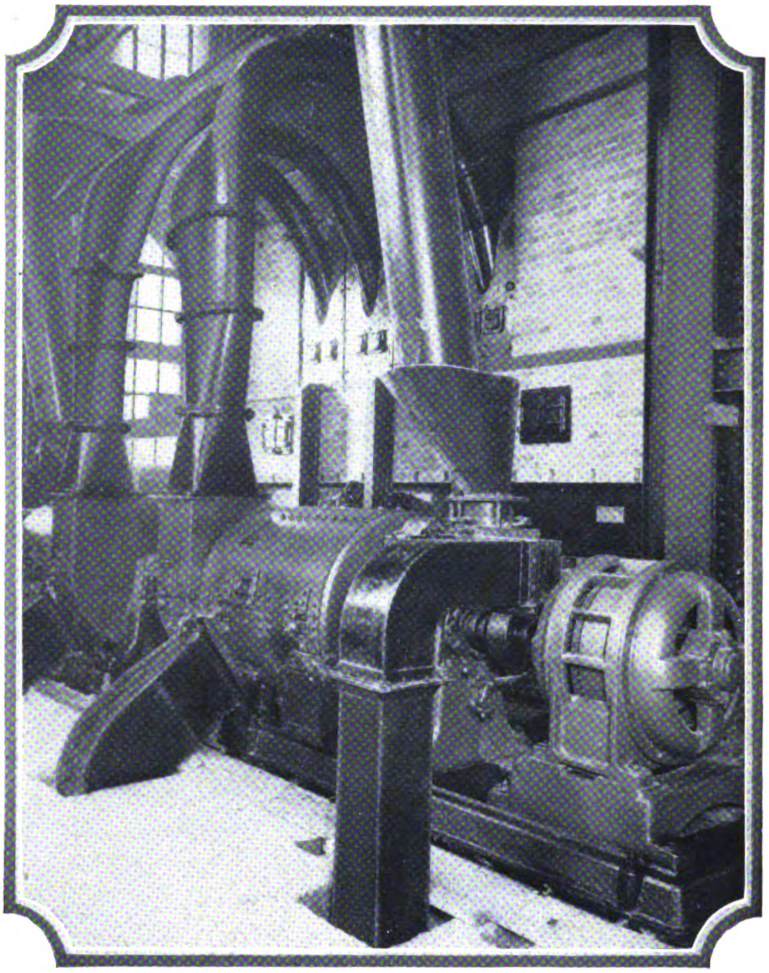
Courtesy of U. S. Air Corps

AND ON INTO THE NIGHT

The airplane is rapidly coming into its own, but before it can take its place alongside our other public carriers—the automobile, the train, and the steamship—it must be able to furnish the same certainty of transportation service, rain or shine, day or night. The recently developed magneto compass should prove a valuable contribution toward this end

(See p. 190)

In This Issue: *Aircraft Compass Problems* *Burn-out of Lamps* *What is Right in Industry* *A-c. Tube Filaments* *Critical Speed in Shafts* *Turbine-electric Ship Propulsion* *Economies of Paulista Electrification* *Hot-cathode Thyratrons* *Chemistry and Electricity*



Four Burners per Boiler for Pulverized Fuel

The accompanying illustration shows two Aero pulverizers firing a 1015 hp. steam generator through four burners. The Aero pulverizers provide a range of operation from 60 to 300 per cent rating when handling coal of high moisture content and low fusing point ash. Preheated air from the front furnace wall is used for drying coal within the mill. The air duct connections are brought up through the floor, giving a clean cut and accessible installation.

The boiler pressure is 350 lb. per sq. in. The equipment includes superheater, Foster air and water cooled furnace and Foster economizer.

Aero pulverizers and Foster furnaces are designed and installed to meet the specific requirements of each plant.

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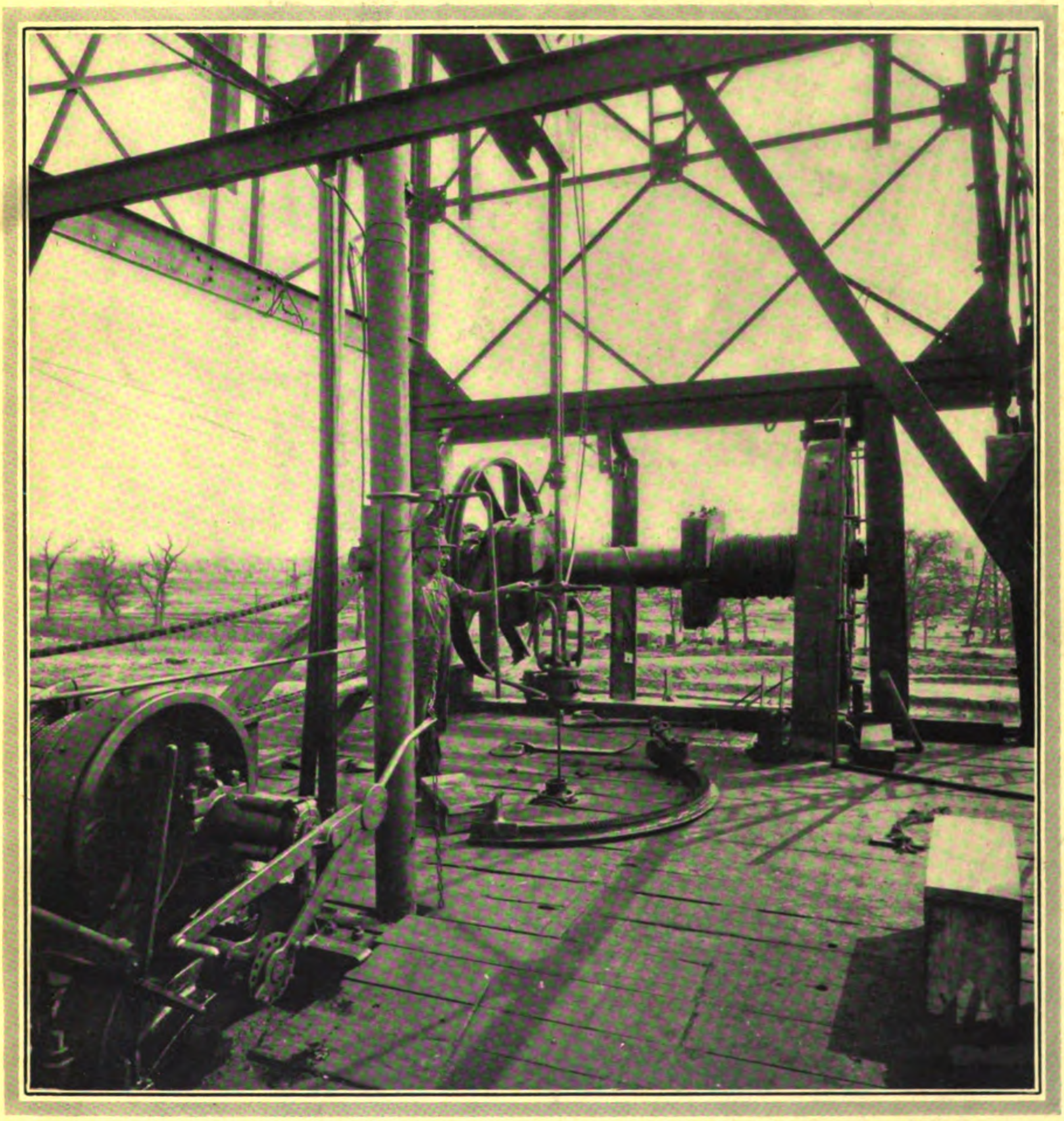
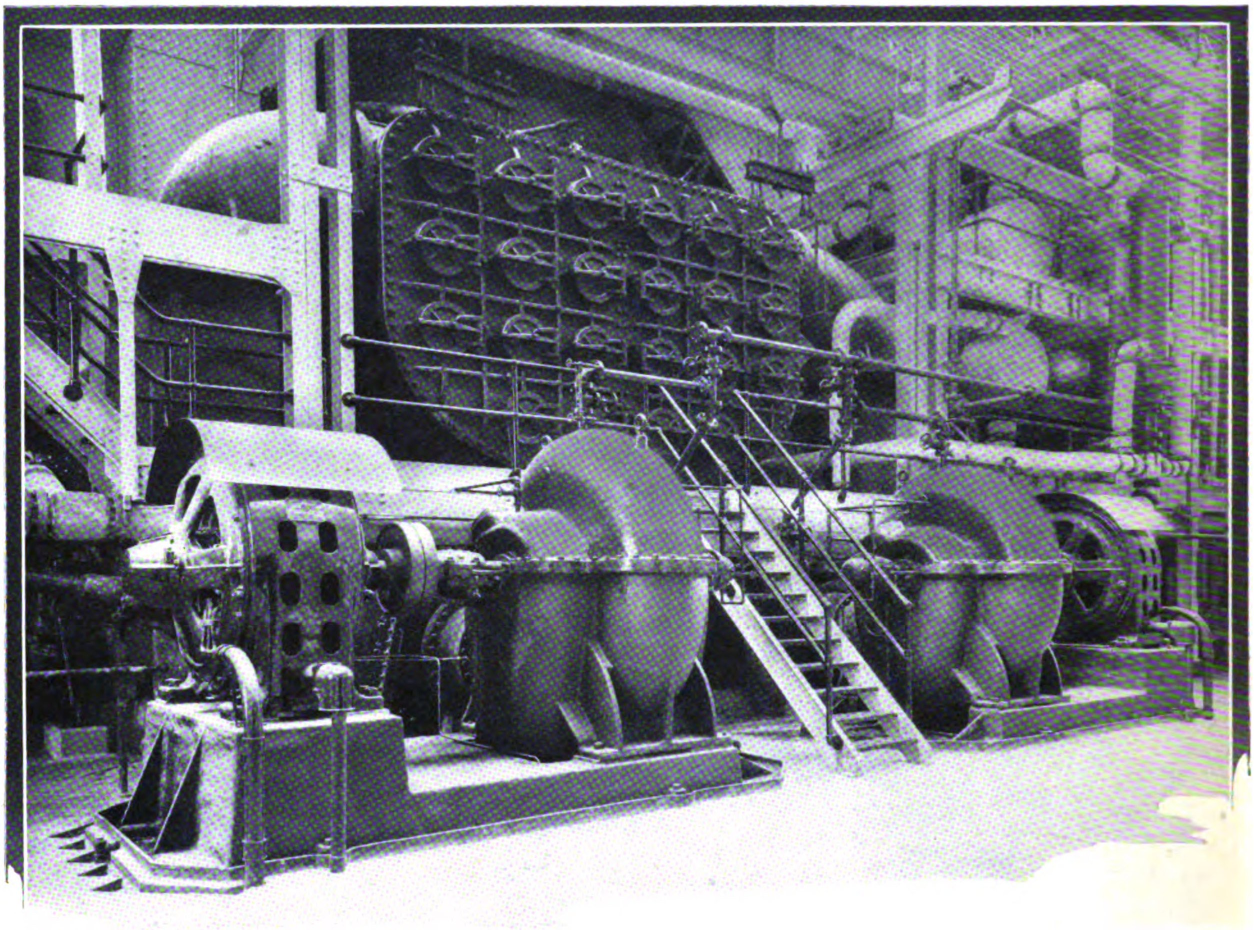


IN THE OIL FIELDS

Electricity is utilized in nearly every phase of oil production. Because of the portability of electric power units, it is readily applied to drilling and pumping operations; as a producer of heat, it is extending its field of usefulness; and in lighting, radio, and other ways it also plays a part in this great industry

In This Issue: *Transformer Protection* *Edison's Lamp* *Production and Care of Oils* *Oscillation Generators* *Transmission Line Surges* *Marine Standards* *Industrial Electric Heating* *Colored Luminous Steam* *New Diesel-electric Locomotive*



45,000 Sq. Ft. Bowl-Shaped Condenser

The second 45,000 sq. ft. Wheeler condenser, installed in the Seal Beach Station of the Los Angeles Gas and Electric Company, is shown in the accompanying photograph. The two 30-in. Wheeler circulating pumps shown in the foreground have a total capacity of 50,000 gallons per minute. The condensing unit operates in connection with a 35,000-kw. General Electric turbine.

The condenser is a two-pass, bowl-shaped unit. The tubes are arranged on double radiating straight lines, forming a large entrance area for incoming, high velocity steam. Decreasing area between each successive row of tubes, provides uniform steam velocity throughout the condenser.

These Wheeler condensers were furnished complete with cast-iron hotwell, twin two-stage steam jet air pumps, Wheeler hotwell and circulating pumps.

Make-up water for plant is furnished by two Wheeler evaporators.

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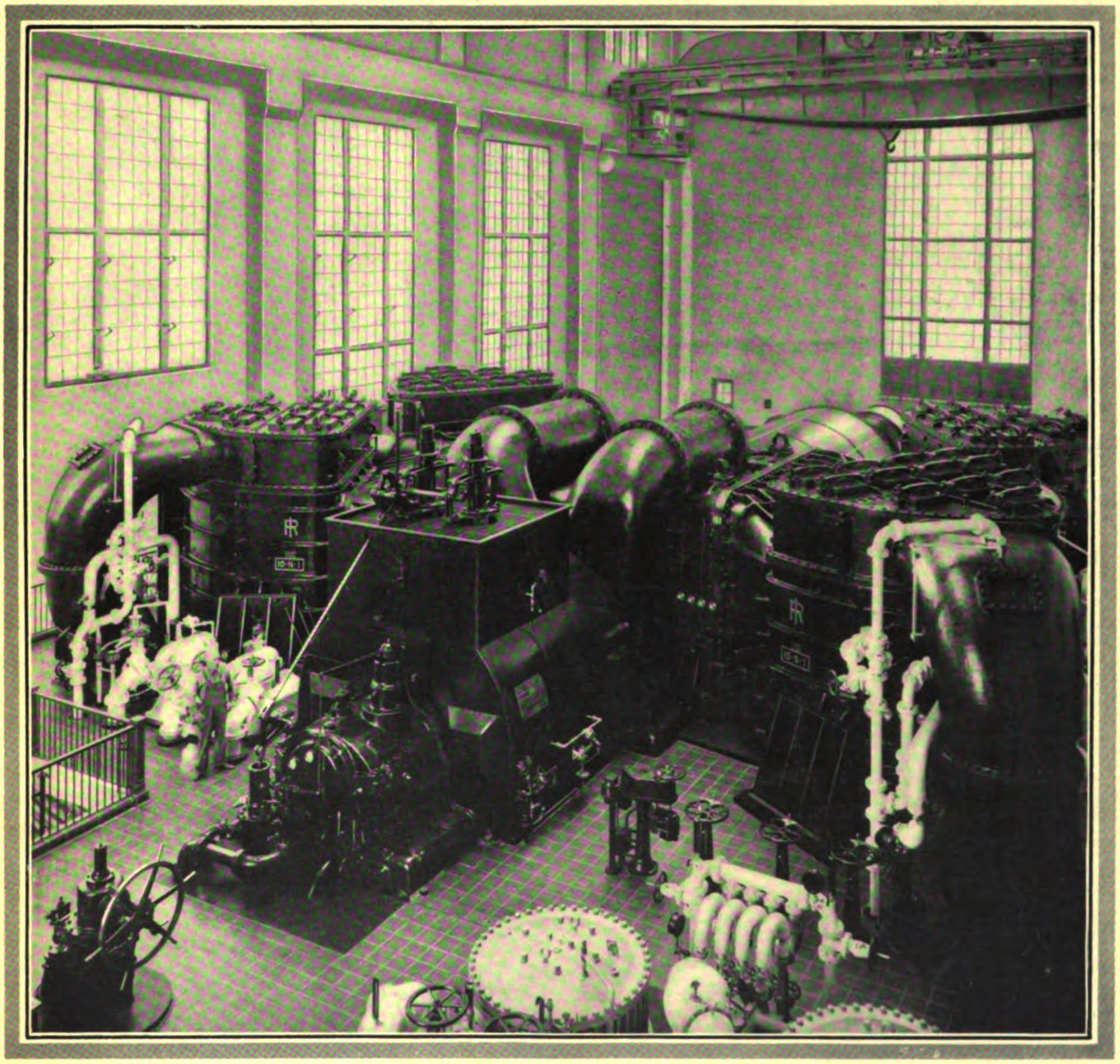
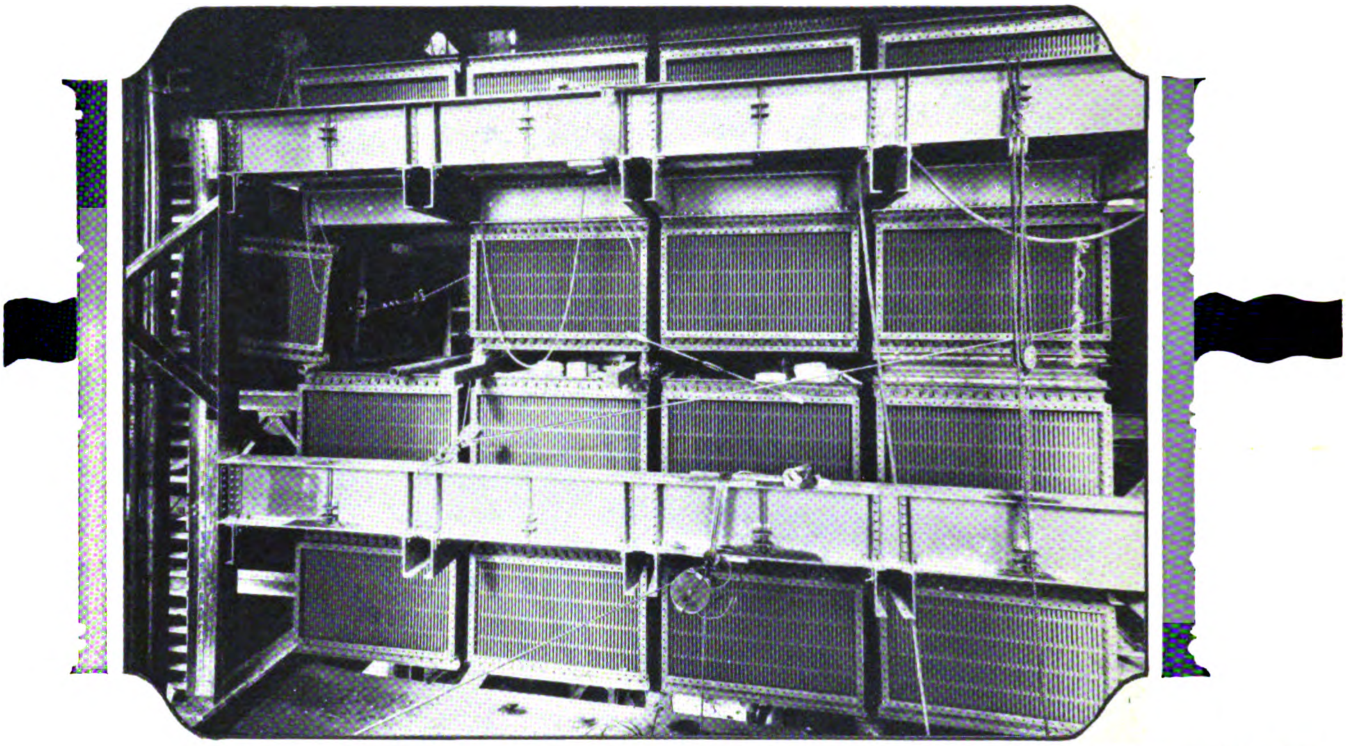


THE STEAM END OF A 94,000-KW. TURBINE-GENERATOR

Tandem-compound General Electric Turbine-generator installed a year ago in the Long Beach Station No. 3 of the Southern California Edison Company. This is a single-shaft machine consisting of a single-flow high-pressure element, a double-flow low-pressure element, a 90,000-kw. main generator, and a 4000-kw. service generator. The turbine exhausts into four vertical condensers

In This Issue: *Grounding of Neutral* *High-tension Cable* *Double-winding Generator*
Metal Arc Welds *Load and Frequency Control* *Field Tests of Super-excitation*
Steam Turbine Design *Electric Ship Economies* *Transmission Apparatus Insulation*



Front view of Foster air heater consisting of 16 interchangeable sections, showing one section being placed in position. With the addition of connecting ducts and asbestos insulation, the air heater will be ready for operation.

Preheating 310,000 Lb. of Air per Hour

The 51,000 sq. ft. Foster air heater, shown above, is designed to preheat more than 310,000 lb. of air per hour from 100 deg. F. to a temperature of 519 deg. F.

It consists of 16 interchangeable sections arranged in groups four sections high. Four such groups are assembled parallel to each other. The sections consist of parallel steel sheets with air passing on one side and gases on the other side of the sheets.

Gases enter at the top of the upper sections and pass vertically downward through the heater. Air enters the lowest sections and flows horizontally through them. Connecting ducts then lead the air to the sections next above, through which it flows horizontally. In like manner, the air passes through the remaining sections of the heater discharging at the front of the upper sections.

This quadruple counter- and cross-flow of gases and air assures an efficient heat transfer for the heater.

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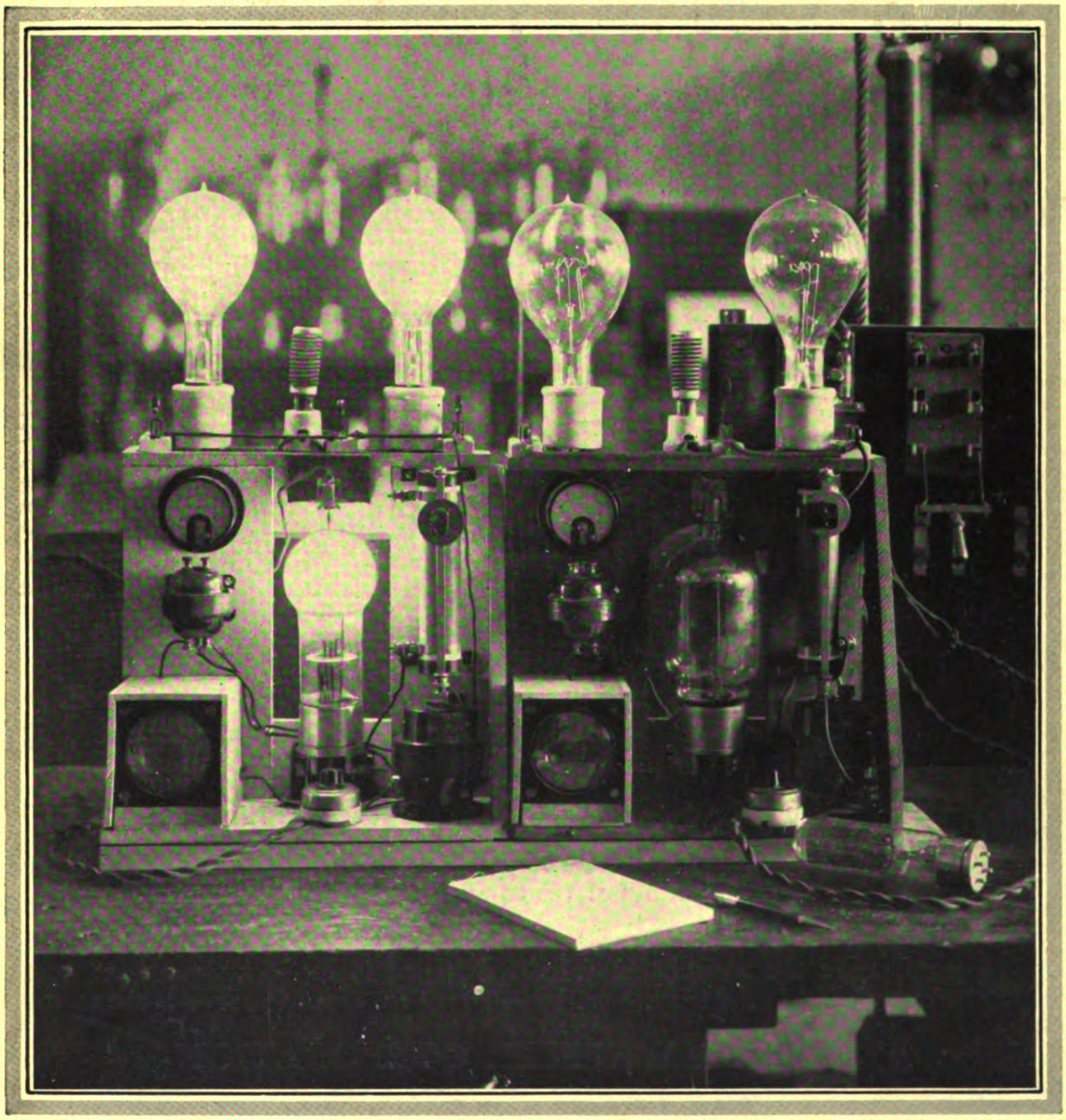
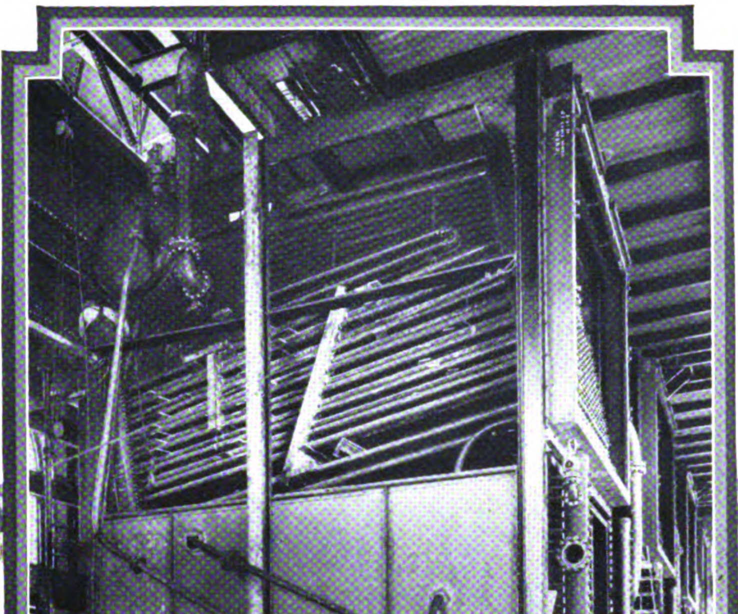


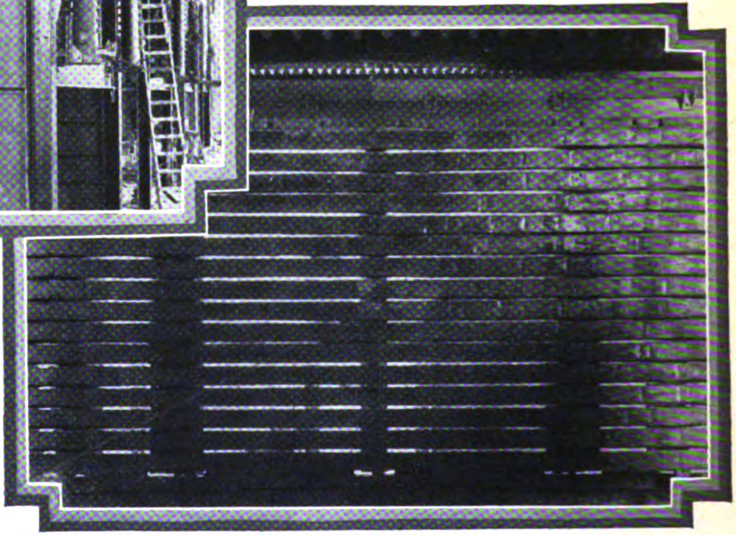
LAMPS LIGHTED OR EXTINGUISHED BY LIGHT

Two demonstration equipments, each consisting of a lens in front of a photo-electric tube, a hot-cathode thyratron, and a pair of incandescent lamps for load. This photograph was taken with less than the photo-electric critical value of illumination. Brighter light falling on the photo-electric tubes would "stop" the left-hand thyratron and its lamps and "start" the right-hand thyratron and its lamps. (*See p. 390*)

In This Issue: *Insulation and Lightning* *Thyratrons* *Missionaries of Science*
Shadow Pictures of Magnetic Fields *Railway Electrification* *Electrostatic Distribution*



(Left) Four 652-hp. boilers being equipped with Foster combination superheaters. The convection superheater is in place between the main tube bank and the boiler circulating tubes. The vertical headers of the radiant heat section are visible at the front of the furnace setting.



(Right) Furnace side of the radiant heat section of the Foster combination superheater. This is composed of seamless forged steel elements and presents a flat surface to the fire.

Uniform Superheat at the Throttle

A virtually uniform degree of superheat over widely varying operating loads is a characteristic of the Foster combination superheater.

The 652-hp. boilers, shown above, will operate at a pressure of 325 lb. per sq. in. and with a superheat of 245 deg. F. The Foster combination superheaters installed are designed for a variation in superheat of only three degrees between boiler ratings of 100 to 250 per cent.

Foster combination superheaters consist of a convection superheater, located above the main boiler tube bank, piped in series with radiant heat elements placed in the furnace wall. Flat final temperature curve is the result.

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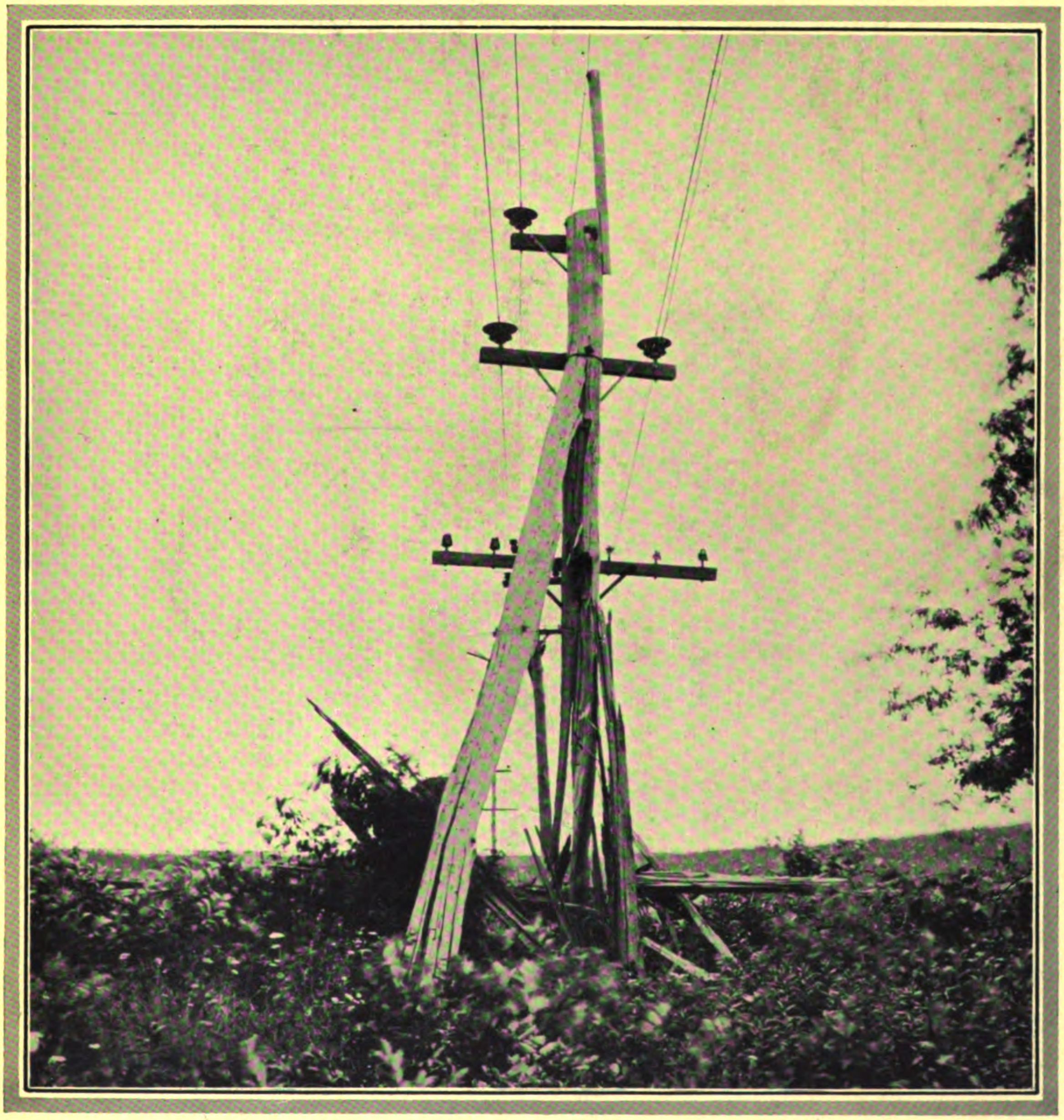
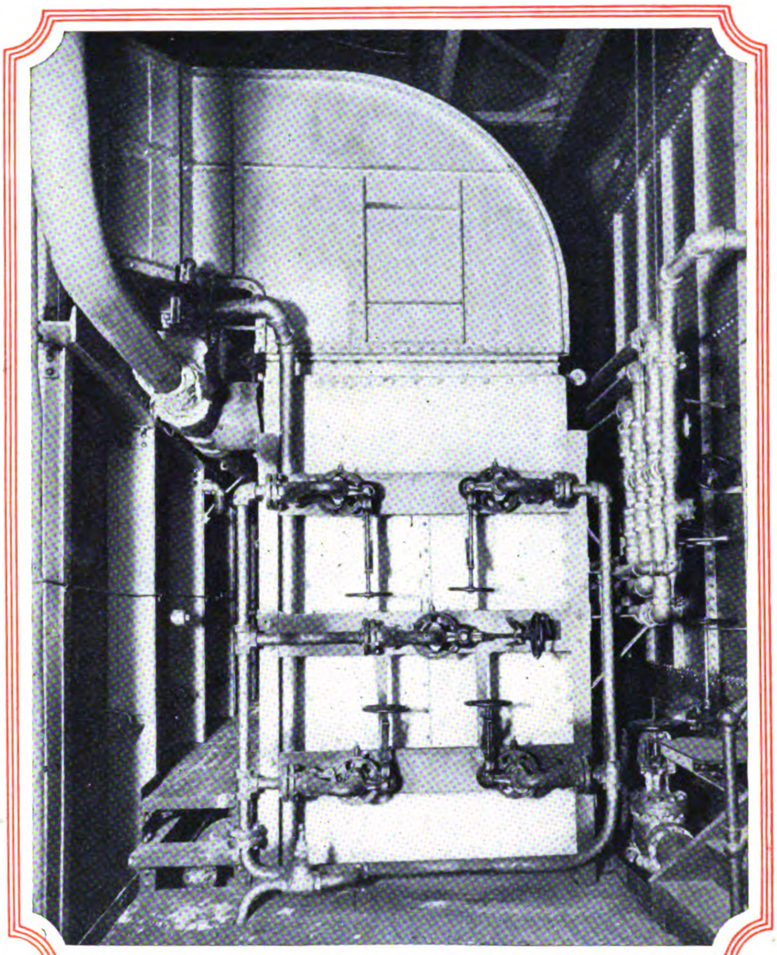


A FREAK OF LIGHTNING

We know much more today than ever before about the general characteristics of lightning but still have much to learn about the why of its erratic behavior in such an instance as this where a direct stroke shattered a transmission-line pole. (Information about the performance and application of lightning arresters appears on page 428)

In This Issue: *Lightning Arresters* *Arc-welding for Pipe Line Construction* *Operations in the Limestone Industry* *Weather Maps* *Resistance of Conductors* *Arc-welding in Railroad Shops* *Electric Heating* *Internal Combustion in Railway Service*



Recovery of Heat From Gases Leaving the Boiler

A most effective and efficient method of reclaiming heat from the gases leaving the boiler is provided by the Foster economizer. The heat recovered is transferred to the boiler feed water.

Foster economizers are located close to the last pass of the boiler and occupy space ordinarily taken up by the flue. The design is simple and rugged. It provides the largest possible amount of heat-absorbing surface per unit of space occupied. Foster economizer design, combined with counter-current flow of gases and water, results in maximum heat transfer for the equipment.

The first Foster economizers, installed ten years ago, are today in successful operation without reduction in their rate of heat absorption. The cost of maintenance throughout this period has been negligible.

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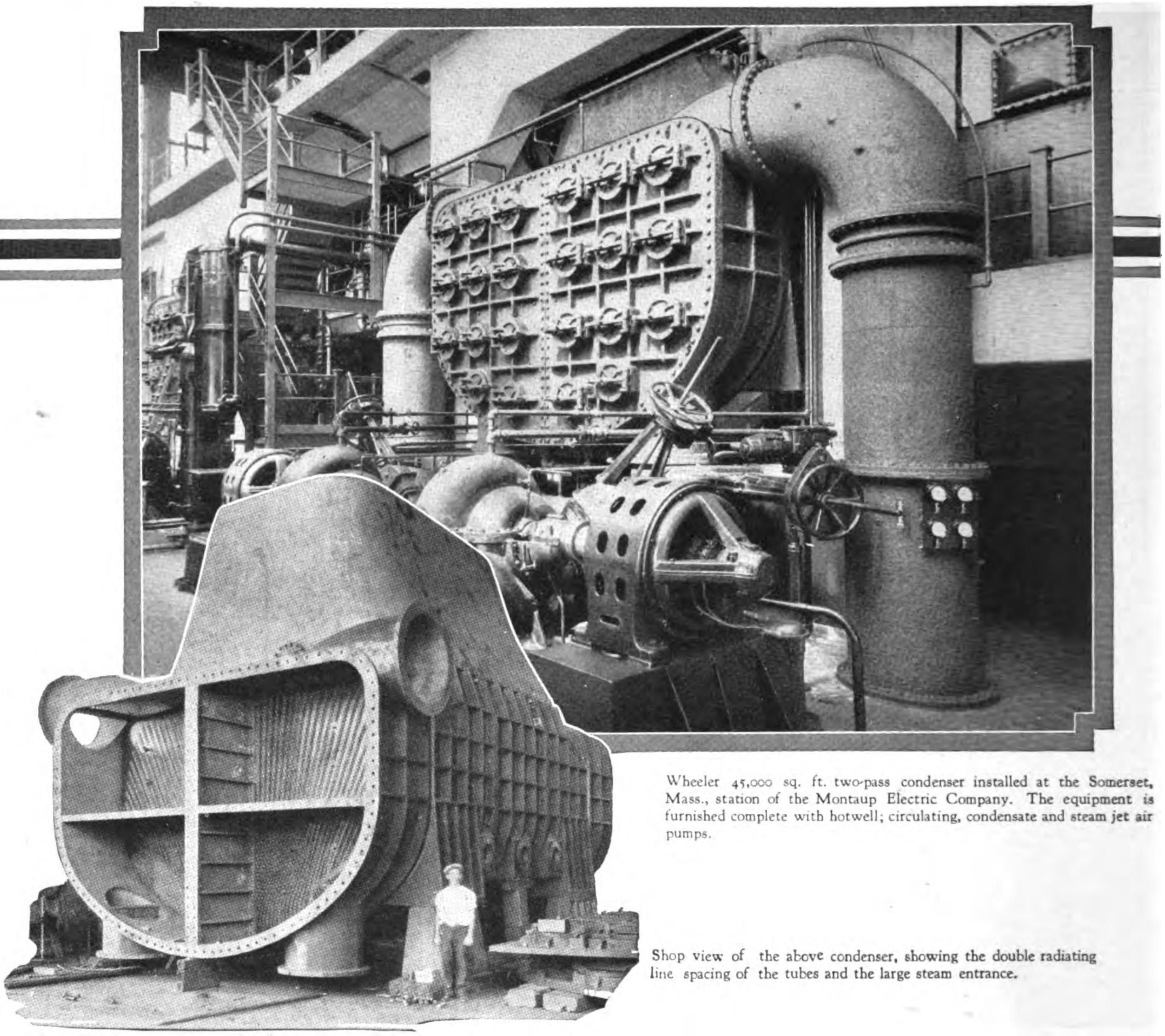
VOL. 32, No. 9 SEPTEMBER, 1929

UNITED STATES

$200,000

We often hear about "gold bricks"—*but these are real ones*. Each bar is worth about $25,000—the eight forming a consignment of $200,000 worth of solid gold from an electrified gold mine to a U. S. Mint. The mine and its equipment are described in this issue

In This Issue: *Electrification of a Gold Mine* *Mercury-arc Rectifier Control* *Electric Motors for Oil Line Pumping* *Electric Locomotive Availability* *Mexican Railway Electrification* *High-voltage Rectifiers* *Testing Power Transformers*



Wheeler 45,000 sq. ft. two-pass condenser installed at the Somerset, Mass., station of the Montaup Electric Company. The equipment is furnished complete with hotwell; circulating, condensate and steam jet air pumps.

Shop view of the above condenser, showing the double radiating line spacing of the tubes and the large steam entrance.

45,000 Sq. Ft. Wheeler Bowl-Shape Condenser

The bowl-shaped Wheeler condenser, here illustrated, is of the two-pass design and contains 45,000 sq. ft. of surface. It serves a 37,000-kw. G.E. turbine-generator.

Large entrance area for incoming high velocity steam is provided by arranging the condenser tubes on double radiating straight lines. Decreasing area between each successive row of tubes assures uniform steam penetration throughout the condenser. Divided water box construction permits shutting down one side of the condenser in case of emergency, without taking the unit off the line.

Vacuum is maintained in the condenser by means of two, three-stage Wheeler steam jet air pumps. Wheeler circulating and hotwell pumps serve the condenser.

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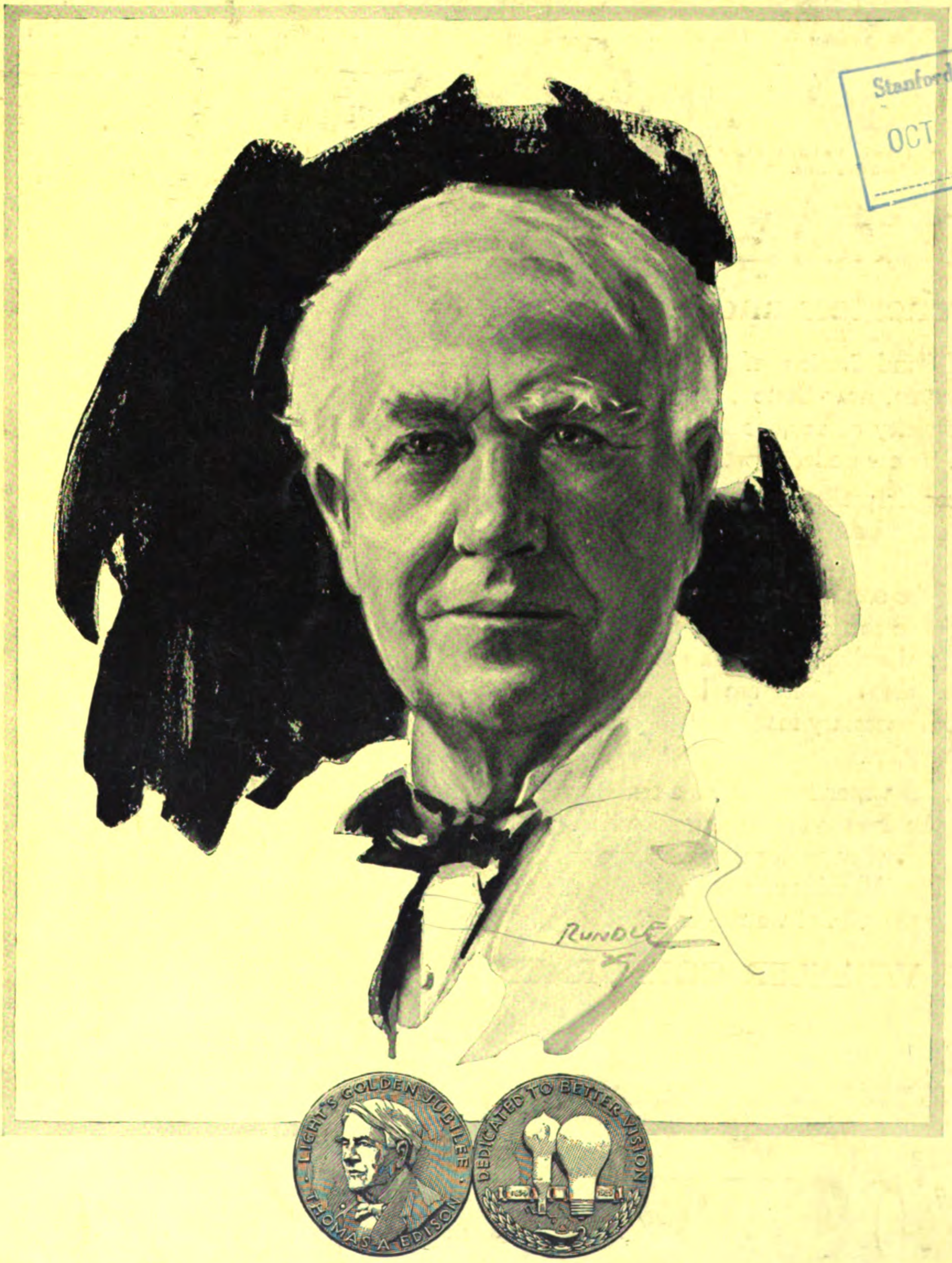
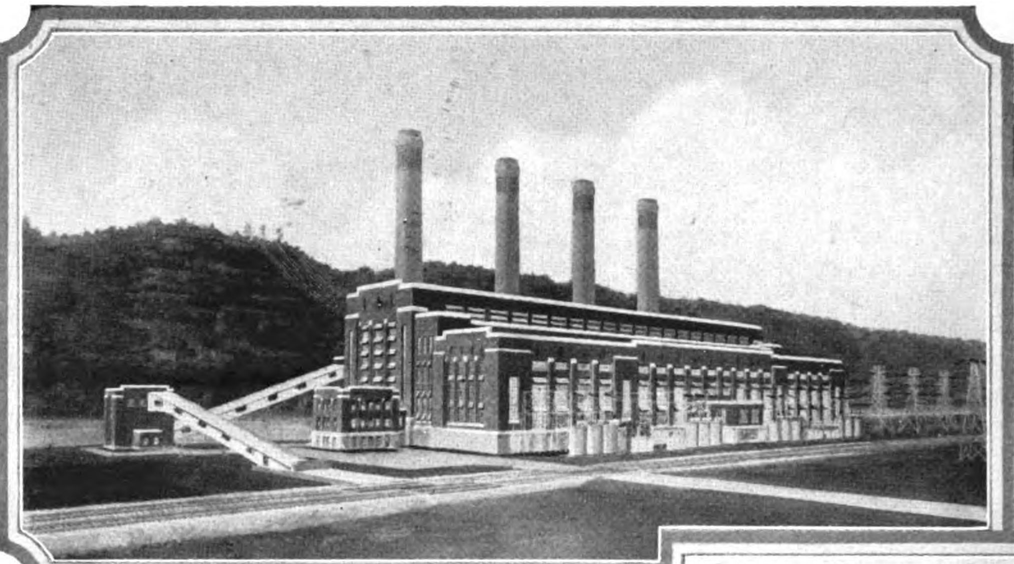

RUNDLE
LIGHT'S GOLDEN JUBILEE
THOMAS A. EDISON
DEDICATED TO BETTER VISION

In This Issue:

- *Light's Golden Jubilee*
- *Flexible Mica*
- *Observation and Brazing*
- *Electrostatic Distribution*
- *Atomic-hydrogen Welding*
- *Railway Electrifications*
- *Crystal Structure and Valence*
- *Beat-frequency Oscillators*
- *Generator Air Passages*



Architect's drawing of the Holland Station near Easton, Pa.
W. S. Barstow & Co., Inc., Engineers.

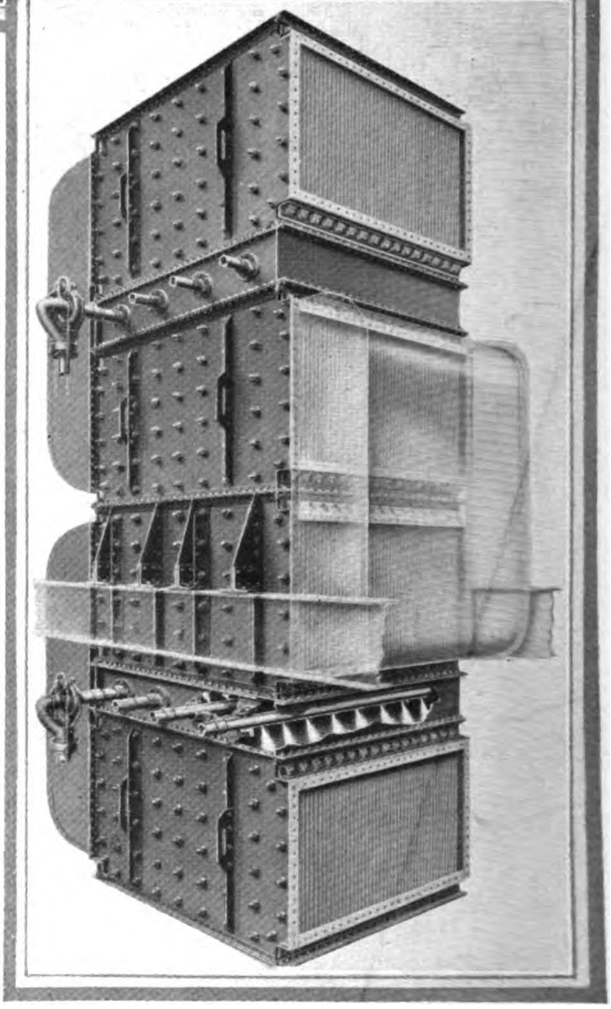
The Holland Station

Air Preheaters and Economizers

The Holland Station of the Associated Gas and Electric System, near Easton, Pa., is designed for an ultimate capacity of 220,000 kw. The initial unit of 55,000 kw. is now under construction.

A Foster air preheater containing 32,450 sq. ft. of surface is included. It is designed to preheat more than 250,000 lb. of air. per hr. to 400 deg. F. The heater is of the sectional-plate type and consists of 10 interchangeable sections. Each section is completely fabricated at the shops before shipment. At the point of erection, the sections are bolted into place and covered with necessary insulation to complete the preheater installation.

Boiler feed water is raised to a temperature of 539 deg. F. by the Foster economizer installed. Distilled make-up from raw water for the two 8,000 sq. ft. boilers is supplied by a Wheeler evaporator having the capacity to produce 15,000 lb. of water per hr.



Typical arrangement of 4 sections of a Foster air preheater. placed one above the other. The Holland installation is designed five sections high.

Gases pass vertically downward thru the entire heater. Air enters the lowest section, flows horizontally thru it, and is then led by a connecting duct to the section next above. It flows horizontally thru this section; then to the section next above. In like manner the air flows thru the remaining sections of the heater.

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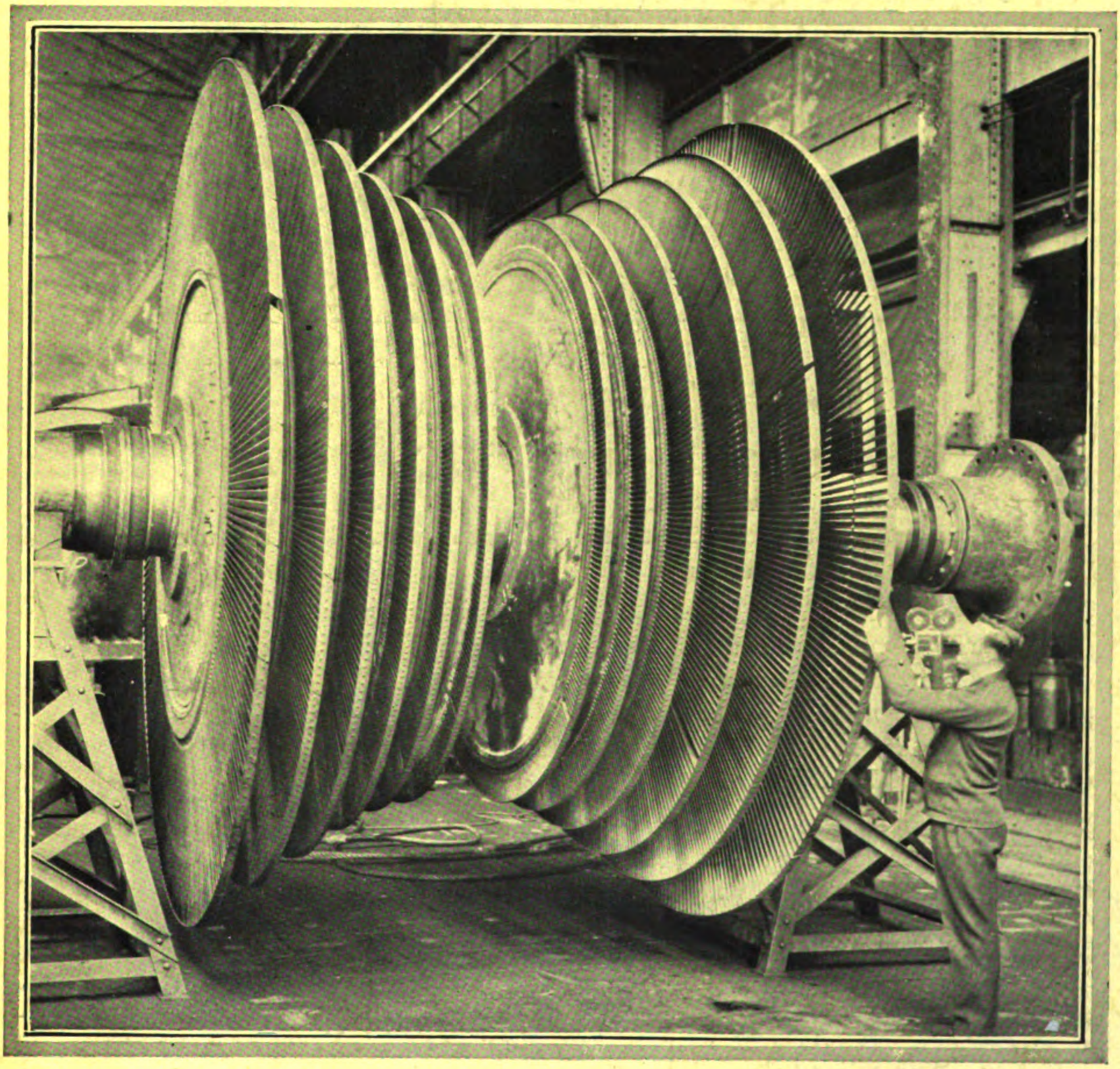
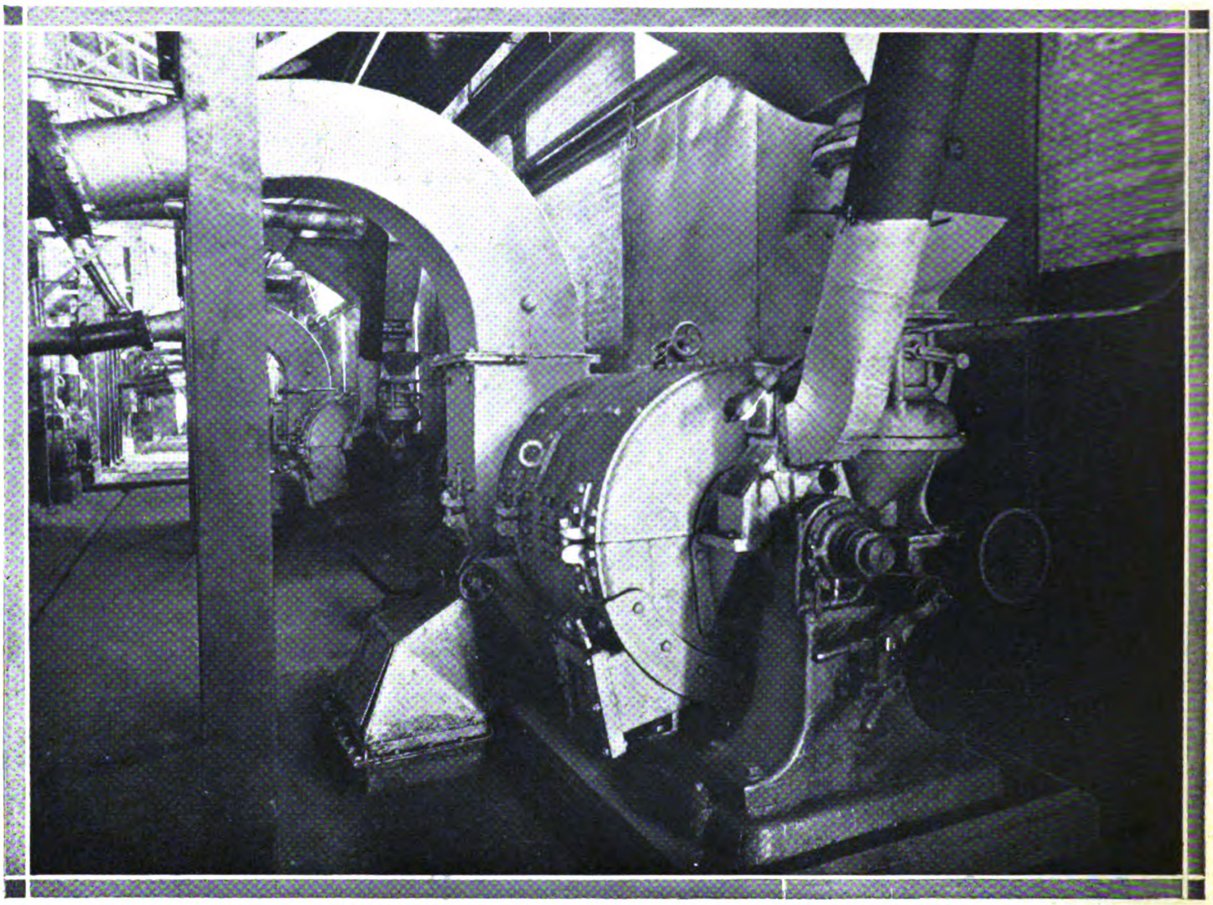


We find
" . . . tongues in trees, books in running brooks,
Sermons in stones . . . . "
and the wealth of nations generated in turbine wheels.

In This Issue: *Ten Articles Recently Delivered as Papers before the World Power Conference and the World Engineering Congress at Tokyo, Japan*



Aero unit pulverizers firing eight 524-hp. boilers. The eight Aero mills are placed in a line down the firing aisle.

Pulverized Fuel Firing

The compact arrangement of the firing aisle in a plant using eight Aero pulverizers is illustrated above. Eight 524-hp. boilers placed parallel to one another are each fired by an Aero unit mill.

Overhead bunkers deliver fuel to the pulverizers through the feeder mechanism at the right end of each machine. Preheated air for combustion enters the pulverizer casing through the duct shown coming from floor at the left of the mill and is mixed with the powered fuel. This mixture of air and powdered fuel is then delivered to burners placed in the front wall of each furnace.

The Aero system of pulverized fuel firing requires a minimum of attention; it affords a simple and direct control of combustion that is practically instantaneous over a wide range of operating loads.

Both unit and storage systems of pulverized fuel firing are installed by the Foster Wheeler Corporation.

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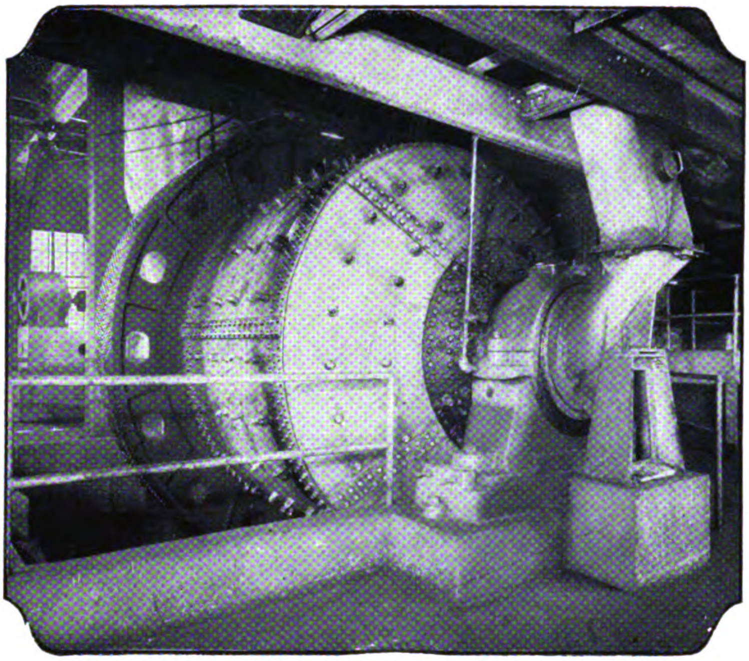
DEVIATIONS APPEAR TEN THOUSAND TIMES MAGNIFIED

Recently-developed direct-reading Electric Gauge as applied to the checking of cylindrical holes for eccentricities—out of round, taper, and local irregularities. The operation is rapid, requires but the minimum of effort, is not dependent upon the sensitivity of human touch, and is therefore ideally suited to the pace of mass production. (*See p. 674*)

In This Issue: ***Modern Physics and Chemistry*** ***Voltage Stresses and Choke Coils***
Transformer Heat Runs ***Lightning*** ***Ultra-violet Radiations***
Electrification of the Mexican Railway ***Glyptal Lacquers*** ***The Electric Gauge***



One of the Hardinge ball mills at the **Metropolitan** Edison Company Middletown, Pa., plant. **This mill has a capacity of 25 tons of bituminous coal per hour.**

Hardinge Pulverizers

at

Metropolitan Edison Company

More than 70 per cent of the coal pulverized by the largest pulverizer at the Middletown Station in 1928 was River Anthracite. The coal is reduced to an average fineness of 95% through a 100 mesh screen.

As River Anthracite is the hardest of coals the supreme test of a pulverizer is the ability to give dependable service while reducing this coal at low maintenance expense.

1.94 cents per ton was the maintenance cost of the Hardinge Mill at Middletown, which pulverized 31,071 tons of River Anthracite and 12,200 tons of bituminous coal last year. This would be good performance on bituminous coal and constitutes a remarkable achievement on Anthracite.

Details of the performance of the Hardinge mill will be furnished upon request.

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